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DEPLOY: Smart Demonstration of Online Water Quality Monitoring on the River Lee, Cork, Ireland

STRIVE

Environmental Protection Agency Programme

2007-2013

Strategy for Science, Technology and Innovation

Comhshaol, Pobal agus Rialtas Áitiúil
Environment, Community and Local Government

Marine Institute
Foras na Mara

Environmental Protection Agency

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EPA STRIVE Programme 2007–2013

DEPLOY: Smart Demonstration of Online Water Quality Monitoring on the River Lee, Cork, Ireland

Smart Catchment Demonstration: Long-Term Deployment of Sensor Monitoring System (DEPLOY)

(2008-ET-MS-4-S2)

STRIVE Report

Prepared for the Environmental Protection Agency and Marine Institute

by

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The EPA STRIVE Programme addresses the need for research in Ireland to inform policymakers and other stakeholders on a range of questions in relation to environmental protection. These reports are intended as contributions to the necessary debate on the protection of the environment.

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Executive Summary

1 Background

Monitoring of European waterbodies will increase over the coming years, in response to the European Union (EU) Water Framework Directive (WFD), and globally owing to climate change and other pressures. Monitoring at river basin level for the WFD is a significant financial burden using conventional sampling and laboratory-based techniques. It is unlikely, however, that the traditional spot/grab sampling provides the required reasonable estimate of the true maximum and/or mean concentration for a particular physico-chemical variable in a waterbody with marked temporal variability. When persistent fluctuations occur, they are likely only to be detected through continuous measurements that have the capability to detect sporadic peaks of concentration. While the WFD does not mandate any particular method of monitoring or chemical analyses, it requires that comparable methods, both of sampling and analyses, be used with good accuracy and precision so that differences among waterbodies and trends can be detected reliably.

The DEPLOY[1] project was a successful technology demonstration, showcasing how state-of-the-art technology can be used to achieve continuous, real-time monitoring of a river catchment. The project involved the collection of in-situ environmental data over a period of 12 months from a network of stations located in the River Lee Catchment, in Co. Cork. DEPLOY has demonstrated that this technology can be used to track fluctuations in a number of water quality parameters such as temperature, dissolved oxygen and pH across a catchment. This, in turn, has demonstrated the benefits of this approach over more traditional means of monitoring that are likely to miss much of the temporal variability associated with these parameters. This technology demonstration of a truly heterogeneous water quality monitoring networked system was one of the first of its kind in Ireland and showed how data could be collected from a number of locations and viewed in real or near real time.

DEPLOY represented an important collaboration among research centres, the National Centre for Sensor Research (NCSR) at Dublin City University (DCU), and the Tyndall National Institute (TNI), commercial partner Intelligent Data Systems and the relevant River Basin District (the South Western River Basin District). The assembled project team had the technical and analytical expertise to successfully deploy, maintain, continuously collect environmental and water quality data and evaluate the effects of long-term sensor deployment on water quality monitoring systems and sensor data from a number of sites. The findings were then disseminated to the widest possible audience through the project website (http://www.deploy.ie).

While the potential of this technology is clear, the DEPLOY project also identified a number of gaps, particularly in the area of in-situ nutrient analysis. Further technological development in this area will be required if the goal of achieving a complete in-situ water quality monitoring solution is to be achieved.

2 Project Achievements Summary

The DEPLOY project team, through the implementation of the sensor network (SN) technologies developed within the project, enabled the study of temporal and spatial variations in water. Data were collected in real time and the performance of a multi-sensor data acquisition system was assessed in a long-term deployment. Based on the deployment results and the extended duration of the deployment, the DEPLOY project provided recommendations on requirements for continuous water monitoring and also reported on reasons for system degradation, including effects of biofouling, corrosion and other physical deterioration. The year-long deployment illustrates the value of a continuous monitoring system to the user, ease of establishment and potential for contribution to a monitoring programme.

1. DEPLOY, Smart Catchment Demonstration – Long-term Deployment of Sensor Monitoring System.

There was a large volume of sensor data (almost 2 million data points) collected at the indicated resolution and granularity. This required the development of new data handling and analysis methods, for example how data are collected, stored and reported, and mechanisms for improved data collection. As a result, the project partners can make significant recommendations for water quality monitoring systems from various perspectives – technical, operational and strategic.

The DEPLOY project has demonstrated the capability of multi-sensor systems to remotely monitor temporal and spatial variations in environmental water quality, identifying short-term events at all sites. This demonstrates the potential for adoption of water monitoring technology as part of a monitoring programme in Ireland. It shows that a system such as DEPLOY could be used as a decision support tool in managing our aquatic environment. This report highlights the key components and main outcomes arising from the DEPLOY project.

The key features of the DEPLOY project deployment are given in Table 1. Main deployment characteristics are included, such as the parameters and the duration of a deployment. The yield denotes the amount of data reported by the SN with respect to the expected optimum, for example based on the sample rate.

Table 1. Summary characteristics of the DEPLOY project deployment.

Project name	DEPLOY
Research area	Water & Environmental Quality
Parameters	• Dissolved oxygen (mg/l) • pH • Conductivity (µS/cm) • Chlorophyll-*a* (µg/l) • Temperature (°C) • Turbidity (FTU) • Depth (m)
Sampling frequency	10–15 min
Duration (days)	365
Yield	97%
Website	http://www.deploy.ie

1 Introduction

1.1 Background

In light of the growing environmental concern and legislation driving environmental protection, there exists a range of national and international policies that drive research in the area of environmental technologies and water quality monitoring. In Europe, the European Parliament and Council passed into law European Commission (EC) Directive 2000/60/EC establishing a framework for Community action in the field of water policy, commonly known as the Water Framework Directive (WFD). The WFD is the most substantial piece of water legislation proposed by the EU and will supersede and amalgamate a number of existing, and more narrowly focused, directives enacted in response to pressures on aquatic environments. The Directive establishes a new, common management system for the delivery of water policy and is concerned with preserving, and improving the quality of rivers, lakes, estuaries, coastal waters and groundwaters (Irvine et al., 2002) that will impact on every aspect of water use – domestic, industrial, agricultural, leisure and environmental conservation.

Monitoring of waterbodies will increase over the coming years, within Europe in response to the WFD, and globally owing to climate change and other pressures. Legislative controls such as the WFD aim to ensure clean, sustainable water supplies in the EU through the achievement of 'good chemical and ecological status' for all groundwater, rivers, lakes, coastal and other waterbodies throughout Europe by 2015, with 'no deterioration' accepted in existing water quality status (EC, 2000). A large part of the compliance requirement to 'good chemical and ecological status of both surface and groundwater' is based on chemical monitoring data. This means in turn that the legal basis of the Directive will be primarily linked to reporting of data, which should be of demonstrated and comparable quality throughout the EU (Quevauviller, 2006). While the WFD does not mandate any particular method of monitoring or chemical analyses, it requires that comparable methods, both of sampling and analyses, are used with good accuracy and precision so that differences between waterbodies and trends can be detected reliably and will represent a powerful management tool only if monitoring data are of reliable and comparable quality (Dworak et al., 2005; Allan et al., 2006).

Currently, the most commonly used method for measuring levels of chemical pollutants is the physical collection of a spot/grab (bottle) sample that is then analysed back in the laboratory (Yang et al., 2002). This methodology is well established and validated, so it has been accepted for regulatory and legislation purposes (Madrid and Zayas, 2007). However, it has a number of disadvantages, including cost, the results often become available only after several days and that it only shows a snapshot of measured variable at the instant of sampling – this is an important factor since levels of pollutants can vary temporally and spatially, and fluctuations associated with episodic events could be missed, or conclusions could be drawn on the basis of transitory high levels (Wagner et al., 2000; Dworak et al., 2005; Allan et al., 2006). When persistent fluctuations occur, they are likely only to be detected through continuous measurements, which have the capability to detect sporadic peaks of concentration. Monitoring using sensor networks (SNs) can achieve the temporal and spatial data frequency required to pick up water quality variability, which is missed using conventional grab sampling approaches. Environmental monitoring is a significant driver for Wireless Sensor Network (WSN) research, promising dynamic, real-time data about monitored variables, enabling researchers to measure properties that have not previously been observable owing to their inaccessibility at appropriate spatial and temporal scales (Cardell-Oliver et al., 2004; Hart and Martinez, 2006; Jannasch et al., 2008).

1.2 Advantages of Sensor Networks

An SN is composed of a number of sensor nodes, designed to transmit data from an array of sensors to a data repository on a server (Akyildiz et al., 2002; Martinez et al., 2006). Depending upon the required application, each sensor node is deployed in or close to the object of interest and can be equipped with different types of sensors, allowing long-term, wide-area, in-situ multi-parameter monitoring (Akyildiz et al., 2002; Yang et al., 2002). Recent technological advancements in the miniaturisation of electronics and wireless communication technology have led to the emergence of WSNs (Goldman et al., 2007; Farré et al., 2009). These WSNs typically have little or no infrastructure and transfer collected data to the user through the use of radio for wireless communication (Yick et al., 2008). The sensor nodes in the WSNs can help to identify the type, concentration and location of specific pollutants, and facilitate the study of environmental processes and aid in the development of response systems (Hart and Martinez, 2006). These WSNs offer the possibility of integrating data not only from local sources, but also from nested or adjacent networks and remote sensing data streams (Rundel et al., 2009).

Currently in Ireland, the Environmental Protection Agency (EPA) operates a national survey of river and stream channel water quality that encompasses over 13,200 km of waterways. The programme involves the sampling of approximately 1,100 rivers and streams at 3,200 sampling stations throughout the State, over a 3-year cycle**,** with the latest such period ending in 2009, using a biological assessment method, which is regarded as a representative indicator of the national status of waters to reflect any overall trends in conditions (EPA, 2009). Although river basin managers and scientific researchers ask significantly different questions in relation to real-time monitoring data, more frequent measurements would be invaluable for both, with in-situ sensors offering the potential of continuous spatial and temporal monitoring of water quality and environmental parameters. Research priorities and water quality programs stress the need for information and comparable monitoring methods to support policy and management strategies in order to detect water quality trends over time (de Freitas et al., 2009). The EPA report entitled *Review of Monitoring and Research to Meet the Needs of the EU Water Framework Directive* highlights the requirement of the WFD to adopt an ecosystem approach to environmental protection (Irvine et al., 2002). The EPA's WFD monitoring programme advocates the use of remote sensing to provide a wider geographical context in monitoring to fulfil the requirements of the WFD (EPA, 2006[1]). It states that electronic sensors providing continuous monitoring help to provide a finer temporal resolution to the monitoring programme, helping to identify occasional or accidental sources of pollution (EPA, 2006[1]).

At present, there are many challenges in the development of continuous long-term water monitoring programmes in Europe. The success of a monitoring system that can provide real-time data on a variety of water quality parameters over long periods of time will rely on the support of teams of researchers in the development of the building blocks of the systems (Greenwood et al., 2008). The development of water quality SNs requires expertise from three different research areas:

1. Sensing;
2. Communication; and
3. Computing.

Within the field of environmental SNs, an essential fourth component is the application of domain knowledge (Martinez et al., 2006). There is a need for researchers across these research areas to work together to develop the 'internet-scale sensing' technology and to scale that technology up in order to validate its performance. While measurement and detection of environmental pollutants can be successful under laboratory-controlled conditions, continuous in-situ monitoring remains the most challenging aspect of environmental sensing. Many sensor systems are ready for laboratory applications but need additional development and a significant amount of in-situ testing before they are ready for deployment in the field as certain issues may not be anticipated (Goldman et al., 2007; Barrenetxea et al., 2008). Before any system is designed and installed, a detailed understanding of the physical environment where it is to be placed is required and the systems must be designed to withstand specific conditions present at each deployment site, including power, environmental ruggedness, calibration drift, quality

1. http://www.epa.ie/downloads/pubs/water/other/wfd/#d.en.13281

control, manufacturing costs, and security (Porter et al., 2009). One of the visions of WSNs, however, is that they will enable remote monitoring of the environment and allow researchers to study and understand the complex trends and variability in water quality at appropriate temporal and spatial scales and to identify whether observed trends arise from natural or anthropogenic sources/causes (Cardell-Oliver et al., 2004; Kininmonth et al., 2007; Rode and Suhr, 2007). The data in these systems may be accessed through on-site downloading or remotely. Remotely acquired, continuous in-situ monitoring provides important early warning information to decision makers, thus allowing them to respond appropriately (Glasgow, 2004).

1.3 Objectives of the DEPLOY Project

The primary objective of the DEPLOY project was to implement a WSN of water quality monitoring stations. In doing so, the aim was to demonstrate how this technology could operate continuously, remain robust and provide an insight into processes involved and how this could better inform decision making for the relevant management agencies. More specifically the DEPLOY project was designed to achieve the following:

- Demonstrate the capabilities of SNs in monitoring the **temporal and spatial variations** in water quality;
- Demonstrate the **performance of a multi-sensor data acquisition** system in a long-term deployment;
- Investigate the **reasons for system degradation**, including effects of fouling, corrosion and other physical deterioration;
- Demonstrate the **data handling** and analysis methods: how data are collected, stored and reported, and improve data collection mechanisms; and
- **Make recommendations** for water quality monitoring systems.

In addition to the above overall objectives, the project enabled:

- Demonstration, site visits and outreach activities for governmental agencies (EPA and Marine Institute (MI)), local authorities (LAs) and the public;
- Publication of results in high-impact peer-reviewed journals and presentation of results at national and international conferences;
- Development of a web page for the project and access by agencies, authorities and, where appropriate, the general public to the data;
- Engagement in discussions with the EPA, MI and LAs with regard to a continuous monitoring programme; and
- Organisation of workshops with various agency and industry bodies to promote the activities of the DEPLOY project and to inform a wide audience of relevant entities as to the activities and results of the project.

2 Background to the DEPLOY Project

DEPLOY is a technology demonstration project that began planning, station selection and design in August 2008. It aimed to show how state-of-the-art technology could be implemented for cost-effective, continuous, real-time monitoring of a river catchment. The DEPLOY project is seen as an important building block in the realisation of a wide-area autonomous network of sensors capable of monitoring the spatial and temporal distribution of important water quality and environmental target parameters. The deployment demonstrates SN capability in collecting real-time water quality data and can act as a test bed to implement and evaluate water quality monitoring systems and deployment infrastructure (wireless data transfer mechanisms, novel sensors, sensor interfacing, etc.).

The demonstration sites chosen are based in the River Lee, which flows through Ireland’s second largest city, Cork. These were designed to include monitoring stations in five zones of the river considered typical of significant river systems and to demonstrate the versatility of the technology available:

1. Lee Maltings station;
2. Inniscarra Pumphouse station;
3. Lee Road station;
4. Inniscarra Databuoy station; and
5. Gougane Barra station.

The live data are available online for registered users at http://www.deploy.ie.

The implementation of the deployed SN provides three key advantages over traditional water quality monitoring mechanisms:

1. Demonstration of benefits of high temporal resolution data;
2. Provision of data from multiple sensors from multiple sites in the catchment; and
3. Provision of data in real time to the user.

The ability of the DEPLOY project to remotely monitor temporal and spatial variations in environmental water quality provides more up-to-date information and could potentially cut overall monitoring costs and provide better coverage of long-term trends in fluctuations of pollutant concentrations, thus demonstrating the potential for adoption of water monitoring technology as part of a monitoring programme in Ireland.

3 The DEPLOY System

3.1 How the DEPLOY System Works

The DEPLOY system is a wide-area network of monitoring stations, delivering data in near real time to end-users. An overview of the system architecture is shown in Fig. 3.1. In this architecture, data are collected from stations installed at various locations in the catchment. Each station collects data at pre-programmed intervals. Data are then transmitted to the DEPLOY servers either by short-range Industrial Scientific and Medical (ISM)-band radio or directly via the Global System for Mobile (GSM) General Packet Radio Service (GPRS) network. The data are then processed and made available in a controlled manner to end-users over the network. The following sections describe the sensors, the core data acquisition system, and the central processing system.

3.2 Sensors

Currently, there is a wide range of field deployable water quality instruments available that have the potential to measure a range of physico-chemical and environmental parameters. The DEPLOY technology demonstration involved the integration of a group of freely available commercial water quality and environmental sensors into a distributed communication network to demonstrate how real-time data acquisition can be implemented.

In selecting the instruments implemented in the DEPLOY project, the partners considered the project requirements, including:

- The selection of typical parameters that are commonly measured by regulatory agencies,

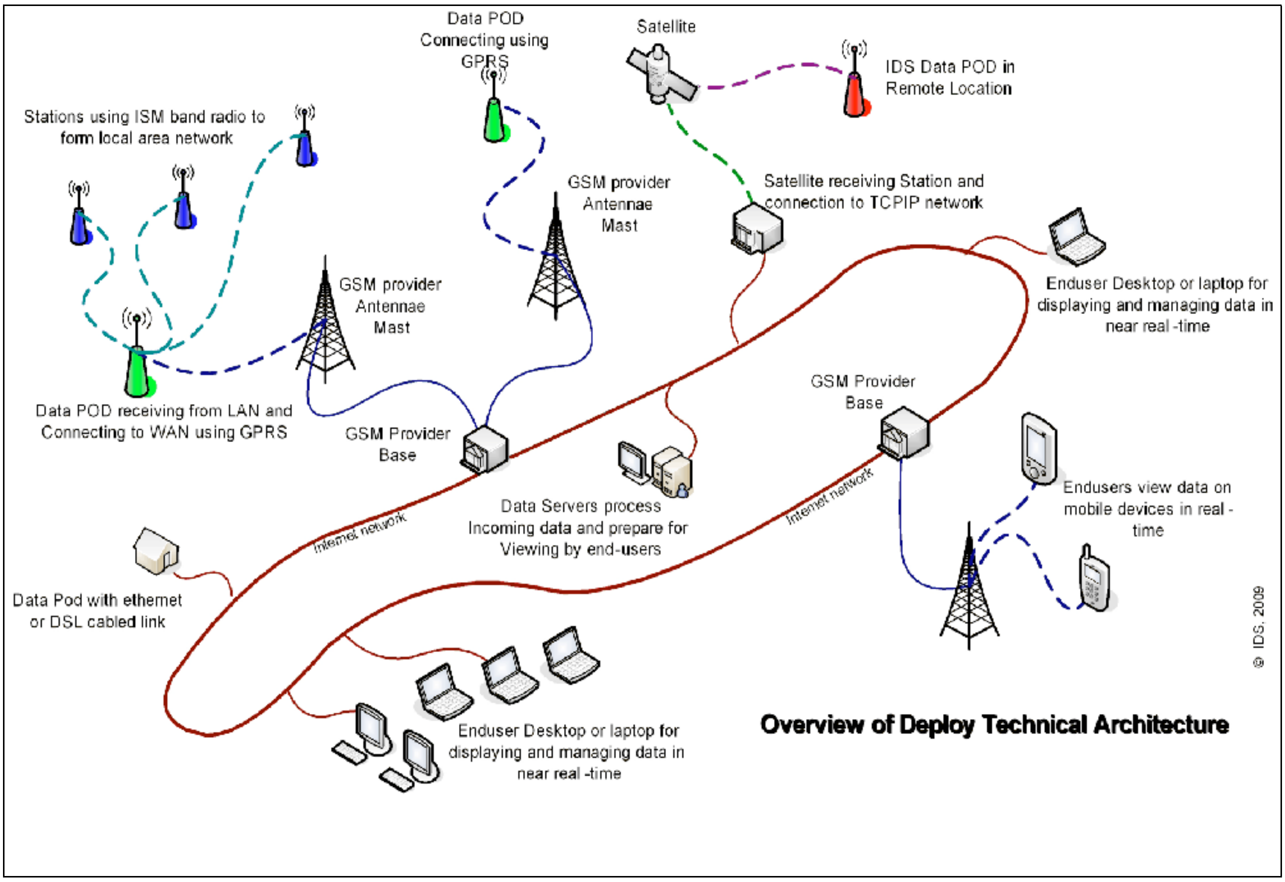

Figure 3.1. DEPLOY system architecture.

including conductivity, pH, temperature, dissolved oxygen (DO), turbidity and chlorophyll-*a*;

- The need for deployment of the instruments for 1 year; therefore, it was important to select sensors that were from reputable suppliers; and
- The instrument budget needed to cover the five sites chosen by the project team.

Based on experience and additional research, sensor systems from three companies were purchased and the specifications for the selected sensors used are listed in Table 3.1. The main instruments purchased included the following:

- 2 × EC3000 from Tyco–Greenspan for measuring temperature and conductivity;
- 3 × EC250 from Tyco–Greenspan for measuring temperature and conductivity;
- 4 × Zebra Technologies D-Opto DO sensors;
- 3 × pH100 sensors from Tyco–Greenspan;
- 2 × GE© Druck PTX 1830 pressure sensors for water level; and
- 5 × Chelsea© Technologies UniLux/TriLux fluorometers.

3.3 DEPLOY Technology

As part of the River Lee deployment two typical station types were implemented.

1. **Station Type 1**
   Station Type 1 was where the instruments were connected to a Tyndall Programmable System-on-Chip (PSoC) electronic system that controlled power to the instruments, read the serial or analog data from the instruments, compiled the measured data into a data message and then communicated this message to and from the IDS DataPOD. The Lee Maltings and Inniscarra Pumphouse were Type 1 stations. The communication between the Tyndall system and the DataPOD could be wireless or through a cabled arrangement (both were demonstrated). The IDS DataPOD listened for the messages from the Tyndall PSoC system and, once received, checked the data for completeness, acknowledged the receipt of the data so that the Tyndall system knew that the data had been passed on successfully. The Tyndall system then waited until the sampling interval has passed and repeated the process. The data messages received by the DataPOD were then appended with a date and time stamp and were logged in solid-state memory on the DataPOD. Once time stamped and logged on these Type 1 stations, the data were then immediately transmitted to the DEPLOY server using the GPRS module in the DataPOD. If for any reason the telemetry on the DEPLOY server did not succeed, then the data were queued for retry until they were successfully transmitted. The processing of the data received at the DEPLOY server is described in Section 3.4.

2. **Station Type 2**
   Station Type 2 refers to where the instruments were connected directly to an IDS DataPOD. At the appropriate sampling time, the DataPOD woke from sleep, powered the instruments, and read the serial and analog data from the instruments. The data were then compiled into a message identical in structure to that from the Type 1 station and were date and time stamped. These data were then transmitted to the DEPLOY server. The Lee Road station and the Inniscarra Databuoy transmitted data as soon as they were received but the Gougane Barra station only transmitted data after an elapsed period (e.g. after 10 sampling cycles). At Gougane Barra, delayed-mode telemetry (message queuing) was implemented to demonstrate low power mode.

These stations which were implemented as part of DEPLOY can be described in three parts:

1. The core network electronics;
2. The physical infrastructure deployed; and
3. The data servers and web application.

3.4 Core Electronics

The heterogeneous nature of the system implementation was realised by a combination of technologies developed by the project partners,

Table 3.1. Specifications for the commercial sensors used in the DEPLOY project.

Provider/Name of equipment	Tyco–Greenspan EC250 Conductivity Meter	Tyco–Greenspan EC3000 Conductivity Meter	Chelsea©[1] UniLux	Chelsea©[1] TriLux	Zebra[2] D-Opto Optical DO sensor	Tyco–Greenspan pH100	GE© Druck PTX 1830
Monitored parameters	Electrical conductivity (EC) Temperature	Electrical conductivity Temperature	Chlorophyll-*a* or Turbidity	Chlorophyll-*a* Turbidity (FTU range)	Dissolved oxygen and temperature	pH	Depth (m)
Detection limits and range	0–2,000 µS/cm (1% of FS) 0–60,000 µS/cm (x1) Temp. (0– 50°C)	0–2,000 µS/cm (1% of FS) 0–60,000 µS/cm (×1) Temp. (0–50°C)	0–100 µg/l 0–100 FTU	Calibrated for 0–100 µg/L 0–100 FTU	0–25 ppm 0–50°C	2– 2	0–7 m 0–2.5 m
Linearity	Temperature 0.2% EC 0.2%	EC ± 1% of FS Temp. ± 0.2°C	n/a	Typically 0.1% of FS	n/a	± 0.1 pH	n/a
Accuracy	1% of FS	1% of FS	0.15% of FS	0.15% of FS	1% of reading or 0.02 ppm	0.2 pH	0.1% of FS
Claimed accuracy	1% of FS @ 25°C	EC ± 1% of FS range Temp ± 0.2°C	<0.01 µg/l	<0.01 µg/l	1% of reading or 0.02 ppm, whichever is greater	± 0.2 pH (±0.2 mA)	1% of FS
Outputs	EC: 4–20 mA Temperature: 4–20 mA	RS232	RS232	RS232	SDI-12	4–20 mA or 0–5 Vdc	4–20mA or 0–5 Vdc
Supply voltage	10–14 V Reverse polarity protected Surge protected to 2 kV	8–30 Vdc (at sensor), or onboard battery pack (option)	11–18 Vdc	8–30 Vdc	8 –15 Vdc, 0.2 Ma standby, 12 mA during sampling	10–14 V Reverse polarity protected Surge protected to 2 kV	10–20 Vdc
Dimensions	Length 442 mm OD 47 mm	Length 490.7 mm OD 47 mm	Length 105 mm (140 mm to end of connector) OD 26.5 mm	Length 105 mm (140 mm to end of connector) OD 26.5 mm	Length 156 mm OD 48 mm	Length 435 mm OD 47 mm	~182 mm long and 18 mm diameter
Weight	950 g (Delrin)	950 g (Delrin) plus cable weight (665 g per 10 m length)	100 g	100 g	n/a	680 g (Delrin)	n/a

[1]Chelsea Technologies.
[2]Zebra Technologies.
DO, dissolved oxygen; FS, full scale; Vdc, volts direct current; OD, outside diameter;

including reconfigurable low power consumption PSoC-based plug-and-play sensor interfaces (O'Flynn et al., 2007), the Tyndall modular WSN prototyping system (O'Flynn et al., 2005; Barton et al., 2006) (shown in Fig. 3.2), and the DataPOD technology developed by industrial partners IDS-Monitoring. This heterogeneous system incorporated a combination of ISM-band wireless transmission capabilities, GSM data transmission from WSN backbone hubs to the data warehouse, and multiple processor types (Atmel ATmega128L and Texas Instruments MSP430). The demonstration of a truly heterogeneous water quality monitoring networked system was one of the first of its kind in Ireland and showed how data could be collected from a number of locations and viewed in real or near real time.

Key technical features of Tyndall DEPLOY Electronics:

- Compact system based on Atmel ATmega128L microprocessor;
- 433/868 MHz ISM-band data communications;
- Integrated Flash memory;
- Compatible with Tyndall Modular WSN prototyping platform (over 40 different system layers available for different sensor requirements, ISM-band radio frequency (RF) capability, Global Positioning Systems (GPS), etc.;
- Cypress Semiconductor PSoC sensor interface;
- Low power consumption system design; and
- Operates on a 3- to 12-Vdc power supply (compatible with solar energy harvesting).

In addition, some of the software features implemented included:

- Low power consumption operation using duty cycling, and intelligent data sampling and data transmission protocols;
- IEEE 1541 standard Transducer Electronics Data Sheets (TEDS) enabling plug-and-play sensor configuration; and
- Capability for sensor modularity and compatibility, sensor aggregation, sensor inter-operability, sensor fault tolerance and dynamic calibration.

Technical features of IDS DataPOD Electronics:

- Compact package based on Texas Instruments MSP430 microprocessor;
- Wide-ranging input, including analog 4–20 mA or 0–5 Vdc or 0–20 Vdc, RS232, RS485, SDI-12 and pulse counting;
- Integrated GSM used for telemetry and clock synchronisation. Telemetry protocols included direct Internet Protocol (IP) data transfer, File Transfer Protocol (FTP), Short Message Service (SMS) and direct dial;

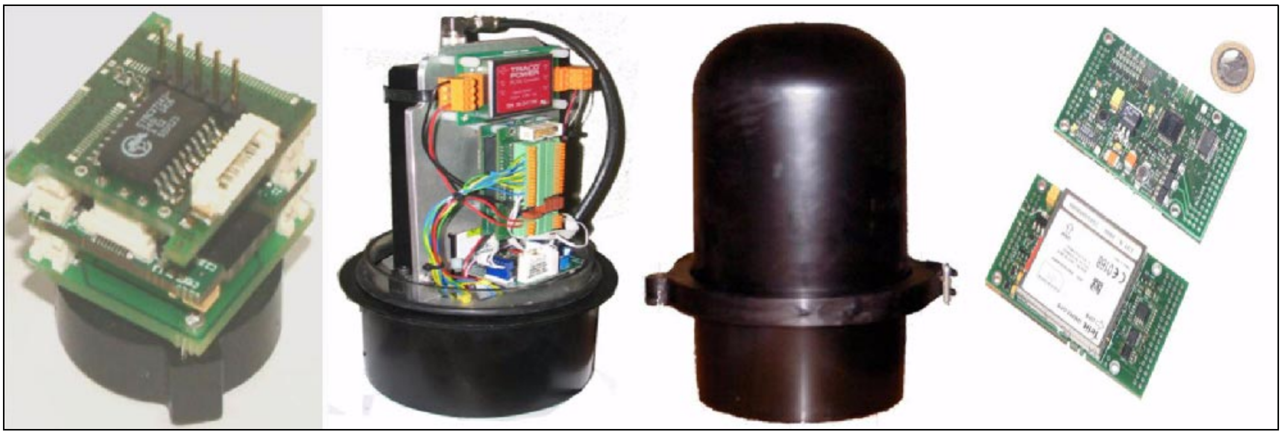

Figure 3.2. Programmable System-on-Chip reconfigurable sensor interface on the Tyndall Stack and IDS DataPOD electronics.

- Options for integrated GPS for position tracking and satellite time stamping;
- Option for integrated Iridium Satellite;
- Integrated watchdog;
- Ultra-low power consumption through intelligent power management;
- Operates on an 8- to 30-Vdc power supply;
- 6 × power control switches (power metal oxide semiconductor field-effect transistors (MOSFETs)) for instruments and other peripherals;
- Integrated solid-state Flash memory 256 MB with SD™ card option; and
- Integrated liquid crystal display (LCD) option.

In addition, some of the software features implemented included:

- Easy to use configurations through a series of structured configuration files;
- Adaptive sampling where the system could change behaviour in response to environment;
- Message queuing where telemetry network failed or where power conservation was paramount;
- Automatic message redirect when primary message destination was not available;
- Remote control of system configuration; and
- Integrated alarm management system allowing the user to define relatively complex trigger conditions.

Further information on the hardware deployed at any of the sites is available from the project partners on request.

3.5 Processing the Incoming Data

The telemetry connection from field-deployed DataPODs and the DEPLOY server based in the IDS offices in Co. Clare, Ireland, used an FTP protocol over the GPRS network. Using FTP, the transmitted data were written to discrete files on the DEPLOY server. The DataLink Parsing App ran permanently on the server and continuously checked and monitored files written to the server by remote stations. Once a file was detected, it was opened by the parser and each record was scanned for completeness. For a record to be complete, it had to contain information on date, time stamp, address and a correct number of data descriptors and data points. If a record was found to be complete, it was then checked by the parser against two criteria:

1. Is this message from a registered station; and
2. Are each of the parameters in the message registered in the system for this station.

If these criteria were met, then the message was parsed and each value was then checked against a list of parameters registered on the server for each station. All valid parameters were then checked against acceptable thresholds, which could be set by the data manager. This constituted a first pass quality control (QC), whereby data that fell outside the expected thresholds were flagged automatically as suspect and were provisionally treated as outliers. These outlier data were written to the database as normal but are not automatically visible to the normal user. Only authorised users were allowed see and use outlier data.

Data from unregistered stations or data that were associated with parameters that were not registered were not written to the database; instead, they were logged as suspect and the raw data were written to a suspect data archive. This suspect data could be easily processed later if, for example, data from a station were registered. Any data that were from a registered parameter or a registered station that fell within the expected thresholds, which were decided on a site-by-site basis by the administrator, were written to the database. The latency for data coming from a station was typically less than 60 s (i.e. the time taken for a measurement to arrive from when sampled to the web is 60 s or less). Once data were written to the database, they were then available to be displayed on the DEPLOY website.

3.6 The DEPLOY Website

The DEPLOY website (http://www.deploy.ie[2]) presents the project data collected from the five project sites (see Fig. 3.3). The key functions on the website became operational at the same time as the stations were commissioned. Data were collected and displayed on the website and the user can select combinations of the different parameters to view at each site. The more visible web interface, which is used to view data and which is accessible to end-users, is only a small part of the system. There is a very substantial back-end system and substantial functionality that is only available to authorised users, such as project partners and system administrators.

3.6.1 Data access options

Access to data and functionality on the system is completely controlled by the user administrator. Access can be controlled at a group/role level or at an individual level. Users requiring access to more data and functionality must request access from the DEPLOY administrators, who will assign the required status. These users will be able to export data, view data in a table format and view longer time series.

2. The DEPLOY website is still active and all data can be accessed on the EPA SAFER-Data website (http://erc.epa.ie/safer/).

3.6.2 User levels

A feature of the website allowed the user to fuse and compare data from all stations on a single page. This level of user was allowed tag categorised comments (referred to as events) on specific data streams. The user could annotate events at a station level and edit data points online and/or change the status from normal to outlier. This assisted users to manage the waterbody under investigation, whereby an event could be flagged to assist in decision making. Therefore, users with a certain level of status on the website could set alarms on the incoming data to the system. These alarm values could be set to monitor the ongoing operation of each station or they could be based on parameter thresholds. The data servers and web application implemented in DEPLOY were part of the IDS Ltd DataLINK system.

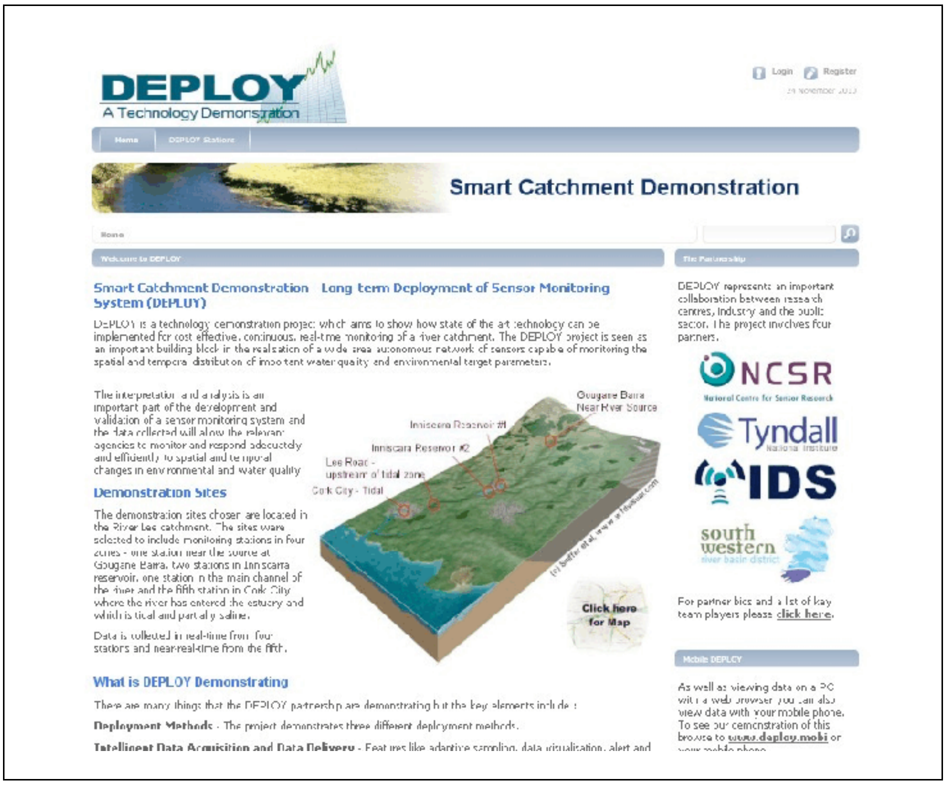

Figure 3.3. Screen grab of the DEPLOY website homepage (http://www.deploy.ie).

In the DEPLOY system, data were received from the sensor network backbone GPRS access nodes using an FTP protocol and were written to a project FTP server. Features/Functions included:

- Controlled access to data and functions based on user name and password. Some data were restricted as were some functions;
- Data visualisation – data from the stations were displayed on a graphic user interface. Users were allowed select data and for what period they could view the data. Data were presented in table format;
- Data-related features, such as data annotation with metadata, data export, graph scaling and data editing, were demonstrated;
- Alarm functions;
- Inter-comparison of data from multiple stations;
- A blog for the project; and
- A simple implementation of Google® maps.

A page from the DEPLOY website showing a typical output from the Lee Road station is shown in Fig. 3.4. The page provides the user with a brief description of what was installed at the station, shows data for a specific period displayed graphically and as a paged table. The user can then select which parameters to view and the period of interest. If the user was logged and authorised with various privileges, he/she could export data, add metadata relating to specific readings, and edit data.

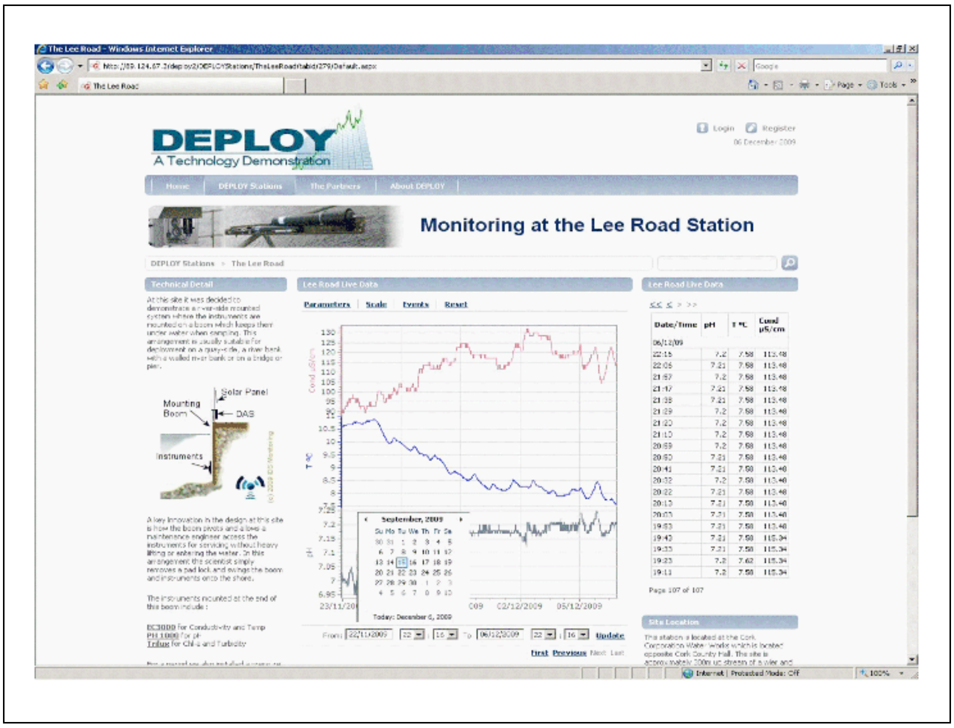

Figure 3.4. Screen grab from the DEPLOY website showing data from the Lee Road station.

4 Deployment of Monitoring Stations

There are several important uncertainty factors associated with the collection of water and environmental quality data from continuous monitoring systems. These include selection of sensors, site selection, location of the sensors in the water column, and the use and calibration of field meters (Wagner et al., 2000; Rode and Suhr, 2007). Ordinarily, as it is not possible to sample the whole area of interest, it is essential that monitoring stations be placed where representative samples can be obtained, and where the data measured represent accurately and precisely the waterbody (Wagner et al., 2000; Miles, 2008). This is not an easy task as scientific considerations need to be understood and addressed, as well as considering other factors including natural, temporal and spatial variability, hydrological waterbody characteristics, climate influence, biological factors, and anthropogenic-induced variability (Miles, 2008). The selection of station locations and technology in the DEPLOY project was motivated by a mix of scientific objectives, accessibility and the requirement to demonstrate the range of technology available at a selection of representative sampling sites.

The River Lee is one of the largest rivers in south-west Ireland, with a total catchment area covering approximately 1,250 sq. km. The river rises in the Shehy Mountains near Gougane Barra to the west of Cork and flows in an easterly direction before reaching Cork Harbour some 85 km to the east. From its upland source, the River Lee flows through countryside punctuated by alternating areas of moorland and small farms before reaching the two reservoirs at Carrigadrohid and Inniscarra, created in the 1950s after the erection of two hydroelectric dams. These elongated reservoirs stretch for a distance of approximately 26 km and have a storage capacity of 45 million cubic meters, with the Inniscarra Reservoir located approximately 13 km west of Cork City. The climate of the Lee Catchment is typical of south-west Ireland, temperate with modest to high annual precipitation, ranging from approximately 2,500 mm per annum in the uplands near the source to less than 1,000 mm per annum in the area around Cork City (CFRAMS, 2008). The monitoring sites chosen by the DEPLOY project were:

- Near the source;
- In a reservoir;
- In the main channel of the river;
- Adjacent to joining tributaries; and, finally,
- In the estuary which is tidal and partially saline.

Tidal influences in the River Lee provide interesting physico-chemical data that show temporal changes in water quality and variations in these regular parameters can indicate anthropogenic influences in the riverine system. The sites on the River Lee extended from Gougane Barra to the Lee Maltings in Cork City. The five sites are shown in Fig. 4.1 and are:

1. A station near the source at Gougane Barra;
2. A tidal site at the Lee Maltings in Cork City;
3. A river bank site at the Lee Road just upstream of Wellington Bridge where the river ends and the estuary begins;
4. In the intake tower for the Inniscarra Waterworks (referred to as Inniscarra Pumphouse); and
5. A databuoy on Inniscarra Reservoir.

4.1 Gougane Barra Site

Originally, it was planned to deploy a small databuoy on the lake at Gougane Barra and permission was secured from the relevant authorities, but local concerns meant that an alternative nearby downstream site was selected. The upper Lee Catchment, where the Gougane Barra site is located, consists primarily of exposed rock and sandstone till subsoils, with areas of peaty topsoil and blanket bogs. Agricultural activities are extensive and consist mainly of hill grazing interspersed with forested areas, which are largely coniferous with pockets of transitional

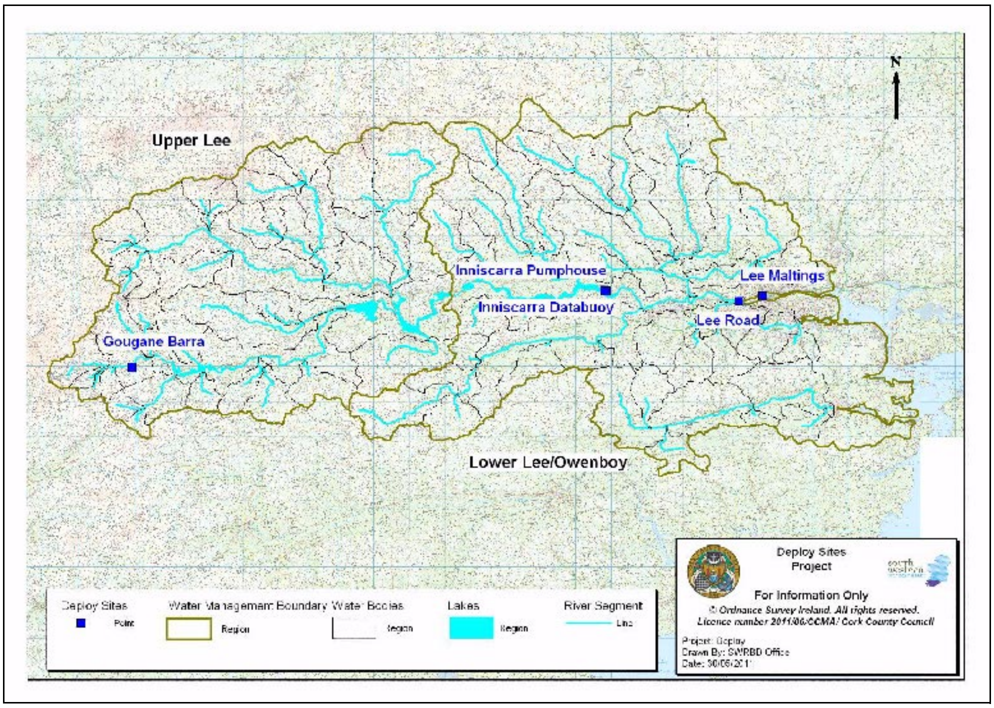

Figure 4.1. Location of DEPLOY multi-sensor sites on the River Lee, Cork.

woodland (CFRAMS, 2008). The equipment at the chosen site was bridge mounted, 1.6 km downstream from the lake at Gougane Barra (see Fig. 4.2). The bridge is a small two-arch structure, where in normal flow conditions only the northern arch is subject to flow. A protective enclosure installed on the downstream face of the bridge housed the instruments, which were attached to the end of a steel pole that extended into the main channel. The river at this point was subject to rapid changes in depth following rainfall, with fluctuations of up to 3 m witnessed after prolonged rainfall flooding the bridge deck.

Figure 4.2. A selection of views around the monitoring station at Gougane Barra.

The station equipment comprised an EC3000 meter for measuring conductivity and temperature and a pH100 meter for measuring pH, chosen owing to the site's remoteness as they required less maintenance than other optical sensors. These instruments were connected to an IDS DataPOD, which controlled power to the instruments, logged and time stamped the data, and transmitted them back to the DEPLOY website. A feature of this station was the demonstration of the low power configuration at the site. The station ran on battery power, data were sampled every 10 min, but, to conserve power, the data were not transmitted in real time back to the web server, instead they were transmitted in batches every 150 min. During the deployment, a single battery pack lasted 5.5 months without recharge or replacement. With less frequent telemetry, battery life could be extended to 1 year. As cost of ownership of the types of systems under investigation within DEPLOY are an important consideration for agencies or industry parties considering implementing a water monitoring strategy incorporating wireless sensor technologies, reducing the number of maintenance visits (e.g. associated with battery replacement) is an important facet of the technology developed.

4.2 Inniscarra Databuoy Site

This was the first station downstream of Gougane Barra and was selected because it allowed the project to demonstrate a system deployed in a lake/reservoir setting. The station was situated on the Inniscarra Reservoir, approximately 200 m upstream from the Inniscarra Pumphouse site and downstream of where the River Dripsey enters the reservoir. The instruments were mounted on an IDS inshore databuoy (see Fig. 4.3).

The buoy was moored in 20 m of water on the reservoir in a central location, approximately 1.5 km upstream of the Inniscarra Dam. Two sets of instruments were placed on the databuoy:

1. The first set comprised a Zebra Technologies D-Opto and a Chelsea© Technologies TriLux fluorometer (see Table 3.1) mounted on the buoy baffle plates, approximately 0.5 m below the surface; and

2. A second Zebra Technologies D-Opto and a Chelsea© Technologies UniLux were mounted on the mooring line approximately 6 m below the surface (see Fig. 4.4).

As with the other stations in the DEPLOY project, the DataPOD controlled the power to the instruments, logged the data and transmitted them to the DEPLOY server at 15-min intervals. The system was powered by a battery pack, charged with solar panels mounted on the databuoy. During the course of the project, the telemetry in the DataPOD was changed from the GPRS FTP-based protocol to an ISM-band 868-MHz

Figure 4.3. The databuoy prior to its placement on Inniscarra Reservoir (left) and anchored in place on the Reservoir (right).

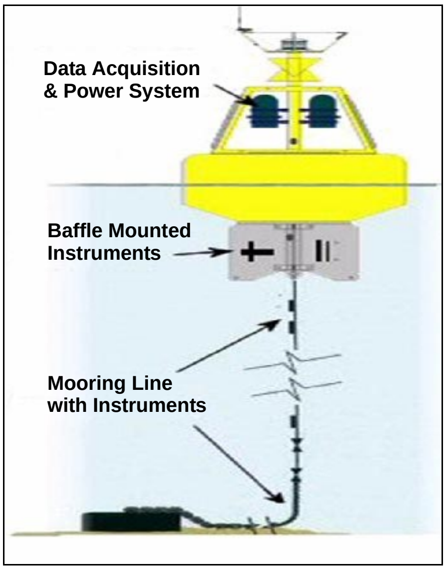

Figure 4.4. Diagram of the data acquisition, power system and instrument placement on the Inniscarra Databuoy.

radio that transmitted to a DataPOD GPRS access node at the Inniscarra Pumphouse.

4.3 Inniscarra Pumphouse Site

The instruments for this station were located in a constant flow-through tank, where water was continually pumped from a depth of approximately 5 m at the intake tower for the Inniscarra Waterworks on Inniscarra Reservoir, which supplies a proportion of Cork City's water supply (see Fig. 4.5). The station is located less than 1.6 km upstream from the hydroelectric dam at Inniscarra and is designated as a potentially heavily modified waterbody (HMWB) under the WFD. The pumphouse was chosen as a monitoring site as it allowed the project to show how a heterogeneous local area network (LAN) could be nested in a main network, demonstrating the type of configuration that might be implemented at key transition points on a river (i.e. where a tributary or other significant inflow occurs) and as the water quality of the reservoir plays a significant role on river water quality downstream, owing to the intermittent discharge of large water volumes from the dam. Water quality in the reservoir has suffered from eutrophication problems in the past and continues to suffer from seasonal algal blooms (Clabby et al., 2008).

The sensors were deployed in a constant flow-through tank, which also housed sampling equipment from Cork County Council and included an EC250 meter for measuring conductivity, a pH100 meter for measuring pH, a Chelsea© Technologies MINItracka II for measuring chlorophyll-*a*, and a Zebra Technologies D-Opto for measuring dissolved oxygen and temperature. The instruments were connected to a Tyndall PSoC interface system that controlled power to the instruments and combined the data from each instrument into a fused data message. The data were then transmitted from the Tyndall system to an IDS DataPOD using an agreed protocol. The Tyndall system was transmitted using a 433-MHz ISM-band radio. These data were received by an IDS DataPOD which was fitted with a 433-MHz

Figure 4.5. Overview of the station (left) and flow-through tank containing sensors at Inniscarra Pumphouse (right).

transceiver and valid messages were time stamped, logged locally and transmitted to the DEPLOY web server using the DataPOD's GPRS module.

The wireless communications protocol implemented at this site was designed to allow flexibility, enabling the administrator to set up the system so that the DataPOD could listen for communications from any station within range and did not need to specifically register or poll for data. A significant advantage of this approach was that it was possible to add other wireless sampling network nodes in the vicinity without reconfiguring the existing installation and, if additional stations added at a later date used the correct protocol, then the DataPOD access node would automatically incorporate them into the network. This set-up potentially allowed for the automatic and seamless inclusion of new permanent, temporary or even drive-by stations to be incorporated into the system at a later date.

4.4 Lee Road Site

This site was located on the river bank next to the intake for the Lee Road Waterworks, approximately 200 m above the weir, representing the end of the River Lee and the beginning of the tidal estuary. This was 500 m upstream of where the river splits into the north and south channels (see Fig. 4.6). The site was at the end of a stretch of river surrounded by agricultural grassland, which serves as a seasonal flood plain. Under normal conditions, flow at the site has a relatively low turbulence, except during flood conditions and immediately after discharge from the hydroelectric dam upstream at Inniscarra.

Sensors deployed at the site included an EC3000 meter to measure conductivity (0–2,000 µS/cm) and temperature, a pH100 meter to measure pH, a Chelsea© Technologies TriLux to measure chlorophyll-*a* and turbidity, and a GE© Druck PTX 1830 to measure the water level. A key feature of this station was the innovative way in which sensors could be accessed for servicing/maintenance, achieved by mounting sensors at the bottom of a pole mounted on railings designed to easily pivot up from a vertical to a horizontal position to allow easy access. The instruments were interfaced with an IDS-Data POD mounted in an enclosure attached to an adjacent railing (see Fig. 4.7). This system was powered by battery that was kept charged by a single solar panel. The system was configured to sample every 10 min and data were transmitted in near real time to the DEPLOY web application. The latency between data collection and display on the web was typically <1 min.

4.5 Lee Maltings Site

This site was located on the quayside within the grounds of the Tyndall complex at the Lee Maltings, at the beginning of a left-hand bend in the river (~70°) towards the upper end of the North Channel of the Lee

Figure 4.6. Overview of Lee Road site (left) and close-up of the site infrastructure (right).

Figure 4.7. Lee Road sensors and mount submerged (left) and removed from the water (right).

Estuary (see Fig. 4.8) and was tidally influenced, with a tidal range in excess of 5 m.

The station equipment consisted of two Tyndall PSoC-based system substations and a Tyndall Hub connected to an IDS POD node implemented in a star network topology, operating in the 433-MHz ISM band. The different components of the deployment comprised:

- **Tyndall Hub IDS POD**
  The node was deployed in a remote location in the Tyndall Building, controlling the sampling time for both the pumped and water-level substations (as described in the following two sections) by wirelessly requesting sensor readings to be taken, and ensuring that they were synchronised and that there was no RF clashing between stations. The initial protocol was designed to keep the sampling time at fixed intervals of 10 min, the idea being that the wake-up call included sampling time information, allowing the sensor nodes to go to full sleep mode for a period of time, thus reducing power consumption.

Figure 4.8. Close-up of the sensors in the sampling tank at the Lee Maltings site (left) and view downstream of the site (right).

Once data from the two substations were received, the readings were compiled into a message format by the Tyndall Hub, which was connected to the IDS POD where it was date and time stamped, logged and then transmitted to the DEPLOY servers and website. The interface between the Tyndall system and the IDS data logger was a serial interface and communications were carried out following the ACKnowledgment protocol. Every time the IDS system accepted a message and consumed the message data, it was expected to send an ACKnowledgment message back to the Tyndall Hub. The Tyndall Hub, for its part, was expected to keep on sending a message until it received an ACK message.

- **Pumped system substation**
  A pumped solution was decided upon at the site, with the sample intake placed approximately 10 m from the river bank above the river bed in the main channel (see Fig. 4.9), as, during the summer months and at low tide, sections of the river bed dry out. During the course of the project, the height of the sample intake was raised to try and reduce the effects of geofouling.

  The pump was controlled by a Tyndall controller integrated into the Tyndall PSoC system. The system woke up upon a Tyndall Hub request, acknowledged the message and reported back the status of the station, specifically, if any sensor had been disconnected or added to the station. Water was pumped from the river channel at fixed sampling intervals (10 min) and analysed by sensors that were mounted in a flow-through tank, allowing easy access for maintenance throughout the year as well as access to mains power as shown in Fig. 4.10. The system turned on the pump for 4 min in every 10 and, when the pump stopped, the water was allowed to settle for 90 s before readings were taken to reduce any potential effects of the pumped water on recorded readings. The readings were compiled into a message format and transmitted to the Tyndall Hub, which was connected to the IDS POD where it was date and time stamped, logged and then transmitted to the DEPLOY servers and website. Three sensors were placed in the flow-through tank measuring:

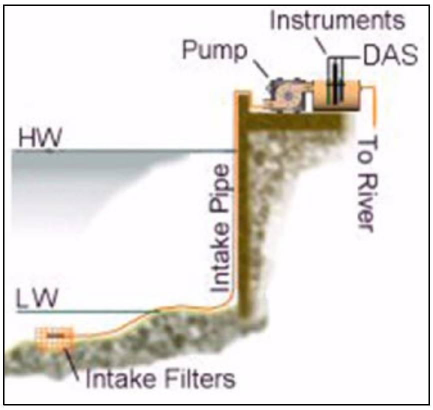

Figure 4.9. Schematic of the pumped system substation at the Lee Maltings.

3. Conductivity (Tyco–Greenspan EC250; 0–60,000 µS/cm),

4. Chlorophyll-*a* (Chelsea© Technologies UniLux; 0–100 µg/l); and

5. Dissolved oxygen and temperature (Zebra Technologies D-Opto).

- **Water-level node**
  This substation, shown in Fig. 4.11, was situated close to the pump system node with a GE© Druck PTX 1830 pressure transducer fixed near the river bed to provide water depth data, as shown in Fig. 4.12. Measurements were taken upon a Tyndall Hub request, after it acknowledged the message and reported back the status of the station, after which measurements were taken and data were transmitted to the Tyndall Hub using a wireless link, which was then passed on to the IDS POD before being transmitted to the DEPLOY servers and website.

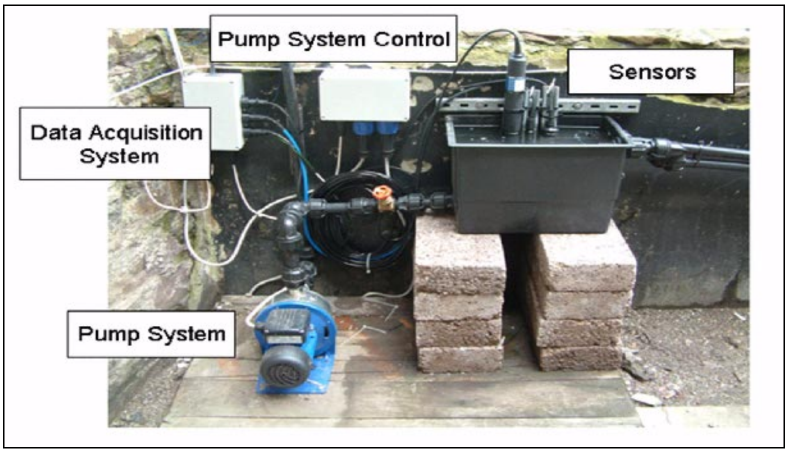

Figure 4.10. Lee Maltings station showing holding tank and pump system.

Figure 4.11. Water-level node at the Lee Maltings.

Figure 4.12. Depth sensor fixed near the river bed.

5 DEPLOY Data

The data collected in DEPLOY are an important output of the project. They were collected from the DEPLOY sites over 12 months, resulting in a large database comprising almost 2 million data points (see Table 5.2). These data consisted of high temporal frequency (usually every 10 min) measurements of temperature, conductivity, chlorophyll, pH, turbidity, depth and dissolved oxygen. Not all parameters were measured at all sites. In addition to these physico-chemical data, additional information on observations at each site was recorded at the time of each maintenance visit; information on sensor performance was also recorded and a discussion blog was established. Primary access to data and functionality on the system was through the project website and was controlled by the user administrator. The data relating to the water quality parameters were plotted in real time and viewed on the website. It was possible to overlay parameters for each site, compare parameters from different sites, and vary the time frame over which they were viewed.

This report provides a series of snapshots of the data, describing some events of interest and highlighting some environmental issues observed during the deployment. It is beyond the scope of the report to show an entire analysis of all the collected data and associated information. An in-depth statistical analysis of the data was not carried out; however, this can still be done. As a result of the project, a large valuable data resource is available for use. These data will be of value to environmental scientists, researchers, computer scientists and teachers/academics as a resource for their work.

In the case of the DEPLOY project, the project administrator can control exactly what data are accessible to different types of users. Registered users of the website are able to export data for their own use, and view those data in a graphical and table format over the whole time series.

The success of a monitoring system such as DEPLOY, which can provide real-time data on a variety of water quality parameters over long periods of time, will allow researchers and policy makers to advance our understanding and protect our resources. The latter relies on the support of teams of researchers in the development of the building blocks of the systems (Kolar et al., 2009). However, in many cases, deployment of these sensor monitoring systems is a labour-intensive and cumbersome task. Environmental influences may degrade system performance in the field in a way that has not been observed during laboratory testing. Long-term field deployments have a strong influence on the function of an SN by controlling the output of sensors, by influencing the existence and quality of wireless communication links, and by putting a physical strain on sensor nodes (Beutel et al., 2009). The adoption of these advanced monitoring tools will be useful only if they are affordable, reliable and produce data that are of comparable quality between times and locations across Europe (Allan et al., 2006). From the 12-month deployment, it was possible to observe how:

- Data quality changes and the reasons for those changes;
- Site-specific conditions affect the data collected;
- There is real value in collecting data every 15 min;
- There is a requirement to maintain and clean sensors frequently to maintain data quality;
- Depending on the season and location, data quality may change due to biofouling; and
- Data can be presented online to suit any user's need, and it is up to the user to decide how the data are presented.

The DEPLOY project did not involve the ecological evaluation of the catchment under study. The joined-up approach of utilising sensors for the assessment of water quality, along with ecological assessment, would have been of great value and should be considered in future.

5.1 Maintenance/Validation

It is widely recognised that it is necessary to carry out regular maintenance on sensors deployed in the aquatic environment. Routine maintenance frequency is generally governed by the fouling rate of the sensors. This rate varies widely depending on location, sensor type, hydrologic environment, and season (Jannasch et al., 2008). Biofouling is the principal limiting factor affecting the operation, maintenance and data quality of long-term in-situ water sensor monitoring. Biofouling refers to the undesirable effects of the accumulation of biota (micro-organisms, plants and animals) on submerged surfaces (ACT, 2003). Aquatic biofouling is often grouped in the literature into four key growth stages – the initial adsorption of a conditioning layer, settlement and adhesion of pioneering bacteria creating a biofilm, and subsequent succession of micro and macrofoulers (Chambers et al. 2006; Whelan et al., 2006). The sequence of biofouling is not predictable owing to the exploitation of substrate niches by higher fouling organisms. However, when an inert substrate is immersed in water, an immediate layer of organic molecules such as sugars and proteins adsorb onto the wetted surface (Chambers et al., 2006; Whelan et al., 2006). Biofouling limits the effective deployment periods of water quality sensors. It diminishes their performance by isolating sensors from the measuring environment and possibly creating microenvironments that alter the chemical concentrations of the parameters of interest (Johnson et al., 2007; Delauney et al., 2010). The performance of temperature, pH and conductivity sensors tends to be less affected by fouling, whereas the optical dissolved oxygen, chlorophyll-*a* and turbidity sensors are more prone to fouling. This is confirmed from data collected in DEPLOY, illustrated in Fig. 5.1. It can be seen that temperature, conductivity and pH readings are typically unaffected by biofouling, whereas the dissolved oxygen and chlorophyll-*a* readings are significantly affected. The data shown represent the situation at the Inniscarra

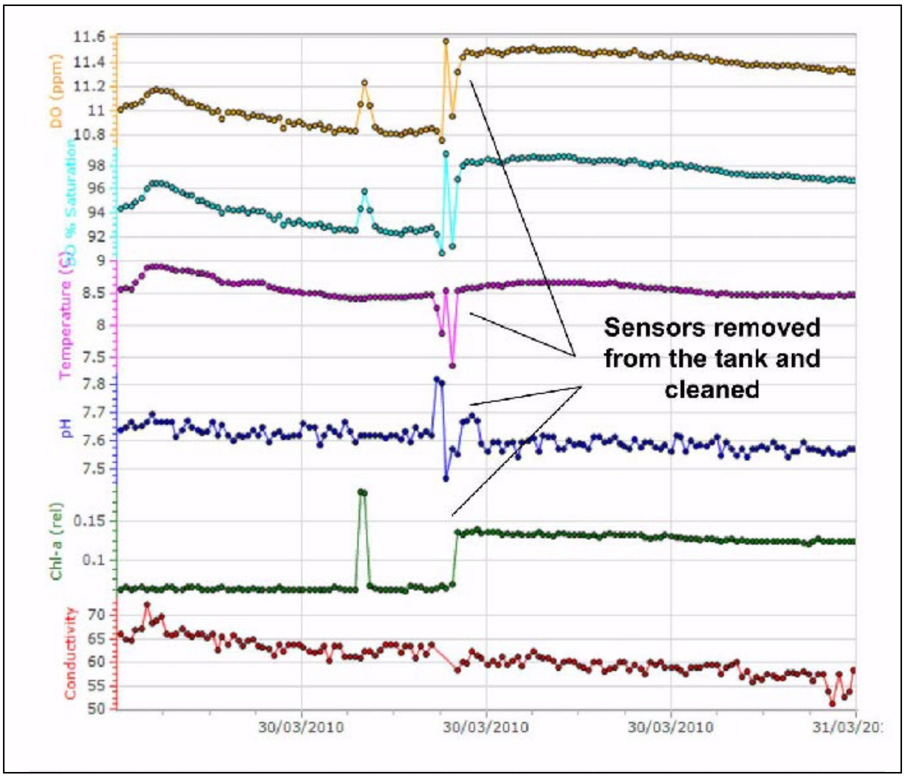

Figure 5.1. Data collected for the Inniscarra Pumphouse before and after a maintenance cleaning visit in March 2010.

Pumphouse site before and after a maintenance visit in March 2010.

This biofouling interferes with and blocks optical paths, reducing and creating barriers to water flow through pipes/hoses, adding weight to the instrumentation and inhibiting the mechanical movement of certain sensor types, thereby compromising collected data (ACT, 2003; Manov et al., 2003). Fouling by larger drifting flora that becomes entangled in physical structures and instruments can inhibit the mechanical operation of pumps, causing physical blockage (Jannasch et al., 2008).

Geofouling (Fig. 5.2) occurs when sediment suspended by tidal currents collects in sensors or in the pumped flow stream. This problem is especially acute in estuaries and during or after heavy rainfall when fresh sediment is washed into the waterbody. Over time these sediments can clog pumped systems, jam mechanical systems, and interfere with sensor readings (Jannasch et al., 2008). In addition to these fouling problems, other physical disruptions (such as pump failure, equipment malfunction, sedimentation, electrical disruption, debris, ice, or vandalism) may also require additional site visits (Wagner et al., 2000). When deployed unattended over an extended period, in-situ sensor readings may become unstable, making drift, repeatability, and accuracy of collected data critical issues for extended deployments, as when intrinsic drift is combined with fouling, sensor data can quickly become uninterruptible (Arzberger et al., 2004). Many potential antifouling solutions have been proposed, including a variety of mechanical cleaning methods, applications of various material types and chemical control methods, as well as surface engineering of biomimetic surfaces, which can increase the period between maintenance visits (Bende-Michl and Hairsine, 2009). However, as biofouling can be specific to the geographical area and directly related to the hydrologic and environmental conditions as well as season, the choice of method will require empirical assessment to find the most effective, taking into account the site characteristics, with sites having high data-quality objectives and requiring a high degree of accuracy requiring maintenance weekly or more often (ACT, 2003; Wagner et al., 2000; Miles, 2008). In situations where power or battery life is not limited, the use of wiper or shutter mechanisms on modern optical instruments may decrease the rate of fouling significantly. Monitoring sites with nutrient-enriched waters and moderate to high temperatures may require service

Figure 5.2. Sensors coated in a biofilm and geofouling observed on sensors deployed in the River Lee.

intervals as frequently as every third day (Wagner et al., 2000). Sensors must be designed to be rugged enough when deployed to withstand the natural processes that occur within the environment, including biofouling, electrochemical corrosion, geofouling, protection from water-borne debris and severe weather conditions (Arzberger et al., 2004; Bende-Michl and Hairsine, 2009). In addition, disruptions as a result of equipment malfunction, electrical disruption, pump failure, and vandalism, may require additional maintenance visits, which could result in the removal of sensors or monitoring stations at certain times of the year (Wagner et al., 2000).

5.1.1 Field cleaning of sensors

Most commercially available sensors can be cleaned with water, a soft bristle brush and a non-abrasive cloth. Heavily fouled material on sensors that resists removal usually can be removed by soaking the sensor in a detergent and water solution (Wagner et al., 2000), but the manufacturer's recommended cleaning procedures should be followed carefully. Optical sensors are more sensitive to fouling, requiring frequent maintenance trips to ensure data integrity and quality. Mechanical cleaning devices that prevent or reduce fouling build-up are available for most commercially available sensors; however, if the sensor is not equipped with a mechanical cleaning device that prevents build-up on the lens before readings are recorded, reliable data collection will be more difficult (Wagner et al., 2000).

5.1.2 DEPLOY maintenance schedule

An important part of the DEPLOY project was the maintenance and validation of both sensors and collected data, which occurred regularly throughout the course of the field trial (Table 5.1). In the 12-month deployment period, all sites were visited on a regular basis for cleaning and validation purposes. In high productivity periods of spring and summer, visits were fortnightly, and monthly otherwise. The length of time between sensor maintenance visits was decided by sensor data readings observed on the project website and by the time of the year.

With regard to the DEPLOY project, maintenance visits were carried out on all sites even if the data did not show any evidence of deterioration in quality. The reason for such frequent visits in DEPLOY was to ensure that data were collected for 12 months. It was found that it was not always necessary to clean sensors on each maintenance visit, depending on the site and the sensor type as described above.

Table 5.1. Maintenance site visit dates between the project kick-off in April 2009 and its end in March 2010.

	Visit period
Site visit 1	14–15 May 2009
Site visit 2	26–27 May 2009
Site visit 3	9–10 June 2009
Site visit 4	23–24 June 2009
Site visit 5	7–8 July 2009
Site visit 6	21–22 July 2009
Site visit 7	5–6 August 2009
Site visit 8	18–19 August 2009
Site visit 9	31 August–1 September 2009
Site visit 10	14–15 September 2009
Site visit 11	7–8 October 2009
Site visit 12	10–11 November 2009
No visit	December 2009
No visit	January 2010
No visit	February 2010
Site visit 13	30–31 March 2010

On each maintenance visit, the hand-held sensors were calibrated on-site with standard solutions prior to taking readings as close as possible to the in-situ sensors. During the winter months (December 2009, January and February 2010), it was not possible to access certain sites due to severe weather conditions and water levels. At the time of maintenance visits, the sensors were removed for a visual assessment (Fig. 5.3), photographed and cleaned if necessary as per the manufacturer's instructions before being returned to the water. In this way, a databank of images was created showing the level of fouling over time and season. For the purpose of DEPLOY, the reason for or the extent of reduction in data quality from heavily fouled optical sensors could then be inferred by examining both the image databank and the difference

Figure 5.3. Fouled sensor (left) and clean sensor (right) following maintenance visit.

between recorded and hand-held sensor readings. Maintenance event tags, images, field notes and observations were uploaded to the DEPLOY blog (DEPLOG) found on the project website.

A range of hand-held sensors of varying degrees of quality and cost was used during the course of the DEPLOY project to measure different variables such as dissolved oxygen, conductivity, pH, turbidity and temperature (see Fig. 5.4). These hand-held devices were all calibrated on-site prior to the collection of data. These devices included the:

- YSI© Professional Plus (YSI© ProPlus);
- Eutech CyberScan PC 300;
- Eutech CyberScan DO 300;
- WTW Turbidity 430 IR; and
- WTW Multi 1970i.

The hand-held sensors were not and should not be used directly to calibrate the in-situ sensors. The aim of their use during maintenance visits was as a general check of in-situ sensor readings and to record any environmental changes that may occur during the maintenance. With the exception of temperature, it is important not to give too much credence to meter-to-meter comparisons (Wagner et al., 2000). Where the readings from hand-held sensors differed from the DEPLOY in-situ sensor readings, further investigation

Figure 5.4. A range of hand-held meters (turbidity, temperature, conductivity, dissolved oxygen, pH) and laboratory reagents and equipment (Winkler method) used during the DEPLOY maintenance visits.

was carried out and resulted in modifications to the system. This also led to the return of some of the sensors to the manufacturers (discussed in Section 5.2). During the maintenance visits, the availability of real-time data, accessible in the field through http://www.deploy.mobi, enabled comparison with the calibrated hand-held sensors and the ability to ensure that the in-situ sensors were functioning correctly after cleaning. This protocol was valuable in the maintenance of the data quality of the sensor system.

Samples of the water at the site of sensor deployment were collected and transported back to the laboratory where analyses were carried out using standard methods for dissolved oxygen and chlorophyll-*a.* Dissolved oxygen samples were analysed using the Winkler titration method, with samples fixed in the field, prior to transportation. Chlorophyll-*a* samples were filtered in the field and stored in cool boxes, being kept as close as possible to 4°C before analysis was carried out in the laboratory.

Data from the analysis carried out in the laboratory and the hand-held meters (Fig. 5.5) were collated and compared with data from the DEPLOY sensor system and the EPA's and Cork County Council's operational and surveillance monitoring sites on the River Lee. The EPA's and Cork County Council's routine operational physico-chemical monitoring involves field measurements of temperature, conductivity and dissolved oxygen and analysis of samples for nutrients, hardness, alkalinity, pH, chloride, and biochemical oxygen demand (BOD). For surveillance monitoring purposes, thermal conditions, oxygenation, salinity, nutrient status, acidification status, and other pollutants are monitored every 3 months (EC, 2000; O'Boyle et al., 2004; Quevauviller, 2006). The full list of parameters analysed monthly by Cork County Council, as well as the parameters analysed by the EPA every 3 months, is given in Appendix 1.

The five sites (Fig. 5.6) on the River Lee and estuary of interest to DEPLOY monitored by the EPA under the WFD operational programme are located at:

1. Inchinossig;
2. Lee Mount Bridge;
3. Lee Road Waterworks Weir;
4. Upper Lee Estuary North Channel, Daly's Bridge; and
5. Upper Lee Estuary North Channel, St. Patrick's Bridge.

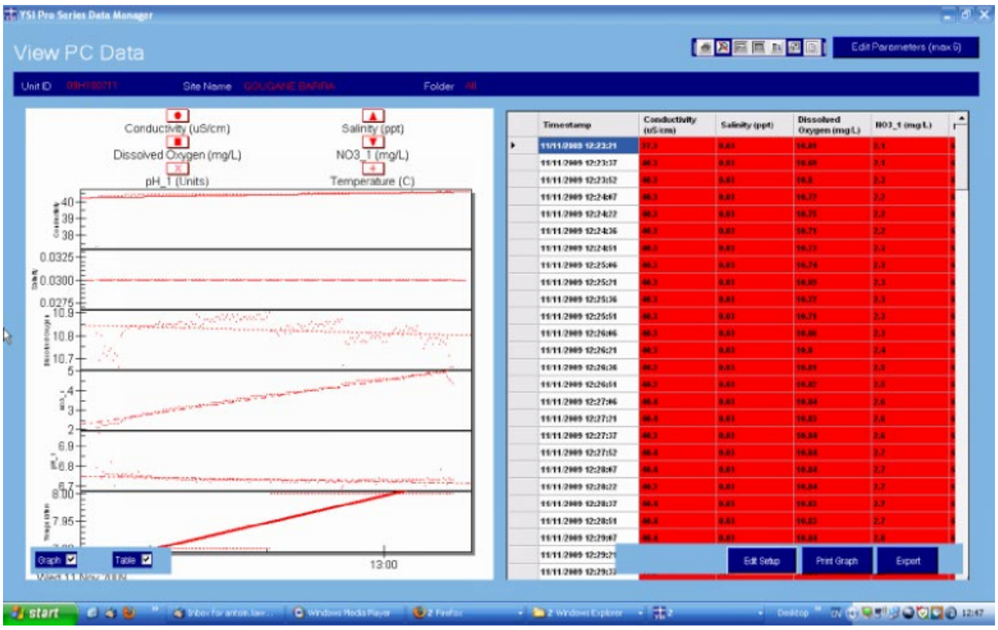

Figure 5.5. Data output from the handheld YSI© Professional Plus collected during a maintenance visit.

Cork County Council also monitors eight sites (Fig. 5.6) monthly on the River Lee at:

1. Carrigadrohid;
2. Bealahaglashin Bridge;
3. Foot Bridge Castlemasters;
4. Dromcarra;
5. Co. Corp. Int;
6. Inchigeelagh Bridge;
7. Inniscarra; and
8. Rooves Beg.

5.2 Collected Data

As noted earlier, the data collected from the DEPLOY project were a valuable output. However, it was outside the scope of the project to evaluate the data statistically. The volume of data collected was large, as illustrated in Table 5.2. The sampling rate of the sensors varied among deployment sites during the year. The default sampling rate was set at 10-min intervals at all sites apart from Inniscarra Databuoy, which sampled every 15 min. However, at certain times for short periods, the sampling rate was increased to every 5 min or extended to every 15 min at certain stations. Over the year-long deployment, sampling at 10-min intervals generated roughly 52,500 data points, while a sampling interval of 15 min generated over 35,000 data points. Table 5.2 displays the total number of data points and the number of sampling events recorded at each station. The data collected from all of the DEPLOY sites are available to view on the EPA SAFER database at http://coe.epa.ie/safer/.

During the project, however, there were periods where data were not transmitted to the web server. This occurred as a consequence of systems being taken off-line for maintenance or as a result of power failure where there was no battery back-up or as a result of technical issues (Fig. 5.7).

(a) The data in Fig. 5.7, relating to the Gougane Barra site, show that 3 weeks data were lost owing to a telemetry system malfunction and, after an

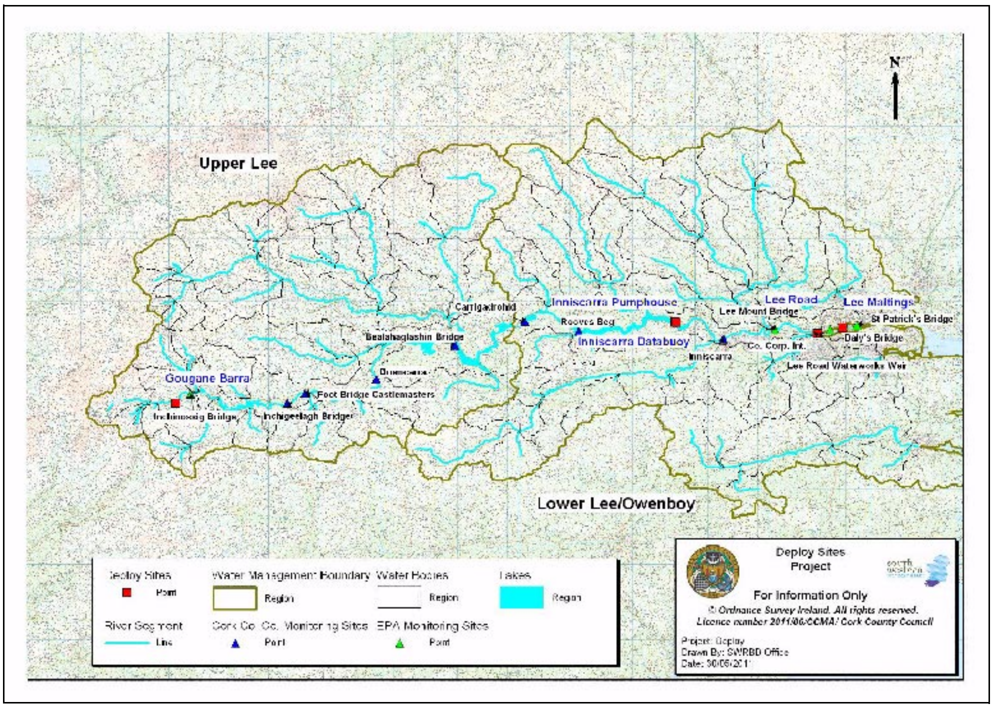

Figure 5.6. Overview of DEPLOY sites (red marker), EPA (green marker) and Cork County Council (blue marker) monitoring sites in the River Lee.

Table 5.2. Total number of data points generated over the DEPLOY demonstration from May 2009 to May 2010.

Site	Total record count	Number of sampling events	% Data recovery
Lee Maltings	428,172	65,693	100
Lee Road	404,051	51,963	99.6
Inniscarra Pumphouse	395,934	57,866	95.95
Inniscarra Reservoir	227,536	36,483	98.34
Gougane Barra	319,998	48,071	94.03
Total	**1,775,691**	**260,076**	**97.6**

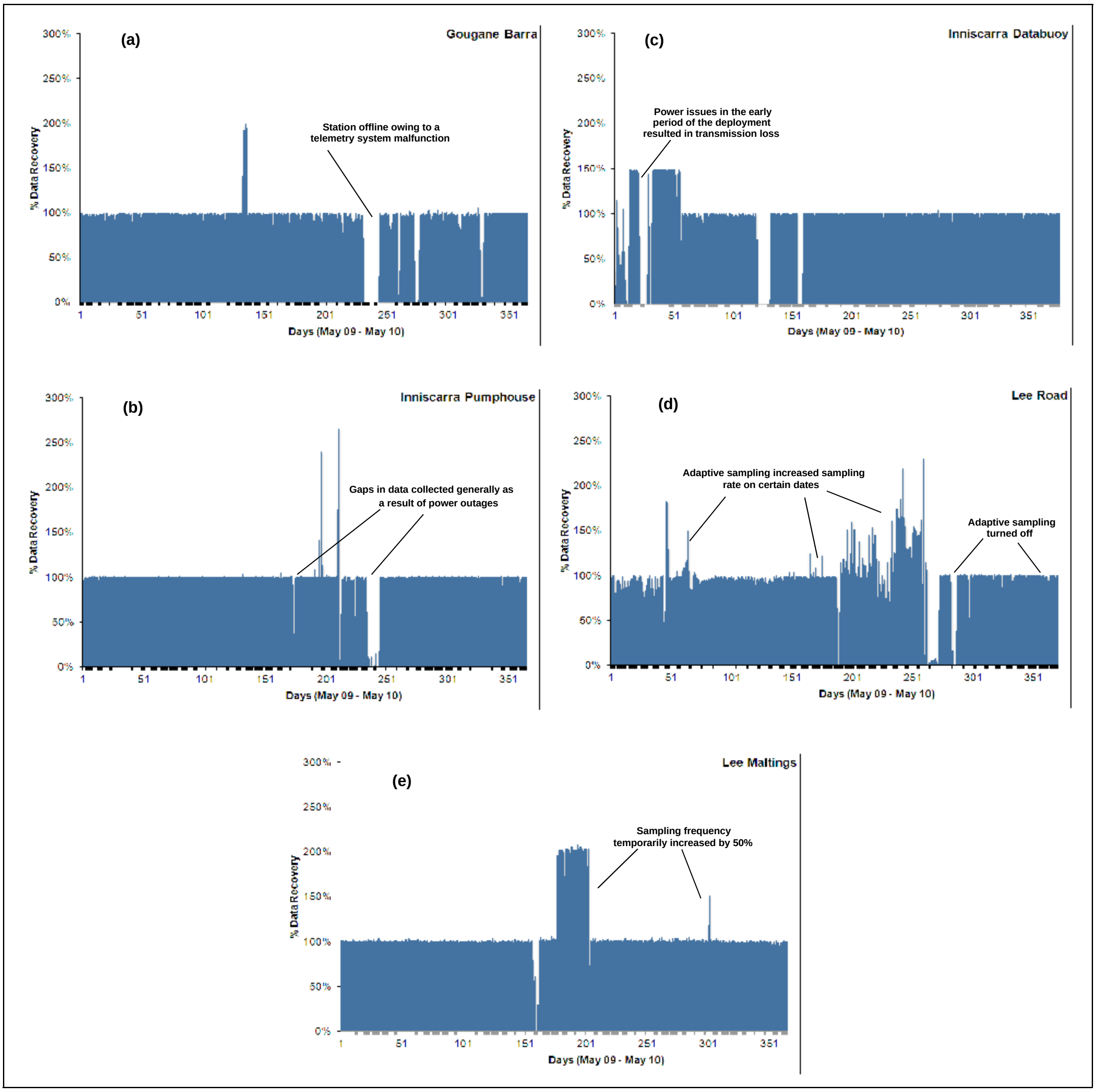

Figure 5.7. Percentage data recovery from DEPLOY sites May 2009–May 2010.

unsuccessful attempt to repair it on-site, the system was taken off-line and removed for repair.

(b) At Inniscarra Pumphouse, routine maintenance by Cork County Council resulted in power being removed from the system, which also reduced flow through the tank in which the sensors were placed.

(c) Data were not collected for a period of 2 weeks on Inniscarra Reservoir when the power system was being upgraded on the databuoy.

(d) Data at the Lee Road were lost for a period during system reconfiguration associated with replacement of the TriLux chlorophyll-*a* and the EC3000 conductivity sensors.

(e) At the Lee Maltings, data were not available for short periods owing to power cuts and a failure of the pump system caused by fouling of the filter intake, which corresponded with consistently high water preventing access to the filter.

As the DEPLOY project aimed to investigate the issues associated with long-term deployment of sensor systems, arising out of the issues discussed in a–e above, a number of modifications to the systems were made and the policy for implementing stations was modified. The electronics and firmware of the systems were upgraded, as was the telemetry module to better handle adverse weather conditions as they arose. These include an upgraded watchdog, greater tolerance of bad instrument data, improved data queuing and, in addition, stations were always equipped with a battery back-up.

Many of the instruments performed well during the long-term deployment; however, a number of issues arose with specific sensor/instruments (see Table 3.1 for instrument details) through the course of the deployment. In particular, the Tyco-Greenspan EC3000 and the Chelsea© Technologies TriLux/UniLux were problematic and these are discussed below.

5.2.1 Tyco–Greenspan EC3000

In the process of preparing these instruments for deployment, an issue relating to an occasional spiking of readings was identified. This was communicated to Tyco–Greenspan Environmental, which conducted some tests but maintained that there was no problem with the instrument and suggested that the instrument driver used by the project team might be malfunctioning. The instrument driver was modified to filter these spikes and the EC3000 was deployed at two stations. While this solution appeared to work in the interim, the frequency of this intermittent data spiking increased over time. After further contact and review, Tyco–Greenspan Environmental conceded that the EC3000 contained a faulty connector assembly and issued a worldwide recall of all instruments to repair the fault.

5.2.2 TriLux/UniLux

Two issues were identified in relation to the TriLux/UniLux instruments.

1. The first concerned its sensitivity to fouling. These instruments are optical instruments and, as discussed in Section 5.1, are known to be susceptible to fouling. Based on the DEPLOY team experience with previous models by the manufacturer and other sensors, it was anticipated that at least 3 weeks' good-quality data would be achieved prior to seeing a deterioration in data during peak fouling periods. However, it was found that at some stations the data from the instruments were adversely affected by fouling after just 1 week. A successful solution to this problem was to invest in an antifouling wiper. However, this required access to mains power supply. As a consequence of the data supplied by the DEPLOY project, Chelsea© Technologies now states to potential customers that, if these instruments are to deployed in situ over a prolonged period of time, they require an antifouling wiper. Chelsea© Technologies has also recently advised the project team that it will make some adjustments to the sensor sensitivity, which it has advised will improve fouling tolerance.

2. The second issue identified by the project partners in relation to the TriLux related to when the instruments were deployed near the surface. In this instance, the sensors occasionally showed negative spiking on very sunny days, which was

not evident on cloudy days. This issue affected two stations (Lee Road and Inniscarra Reservoir) and was reported to Chelsea© Technologies, which took back a number of instruments and reviewed the problem. As a consequence, it designed a shallow water accessory to overcome the ambient light interference.

5.3 Site-Specific Evaluations and Observations

There were several examples at all sites in the DEPLOY project where the understanding of the internal river physico-chemical dynamics was improved by the availability of higher-resolution data on increased temporal and spatial scales. Some examples have been extracted from the data set to illustrate the value of the system and identify some interesting environmental events.

5.3.1 Gougane Barra

At the Gougane Barra station, (described in Section 4.1), the data showed a relationship between pH and conductivity. By using the high frequency data, it was possible to speculate as to some of the potential causes of the sudden fluctuations in the observed parameters at the site. The EPA and Cork County Council take monthly grab samples and analyse them for a wide range of parameters at seven sites in the upper Lee Catchment (see Fig. 5.8). This is done as part of the operational monitoring programme in fulfilment of the WFD objectives.

Figure 5.9 displays pH and conductivity data, two of the physico-chemical parameters taken over the time span of the DEPLOY project from the EPA's Inchinossig Bridge site located 1.5 km downstream from the DEPLOY site at Gougane Barra. Seasonal fluctuation in both conductivity and pH are observable; however, from this graph covering 13 sampling events it is not possible to see or examine any of the potential causative effects of these fluctuations between the sampling dates.

However, from the DEPLOY station data at Gougane Barra, where sampling occurs once every 10 min as illustrated in Fig. 5.10 displaying pH and conductivity from November 09, a more detailed illustration

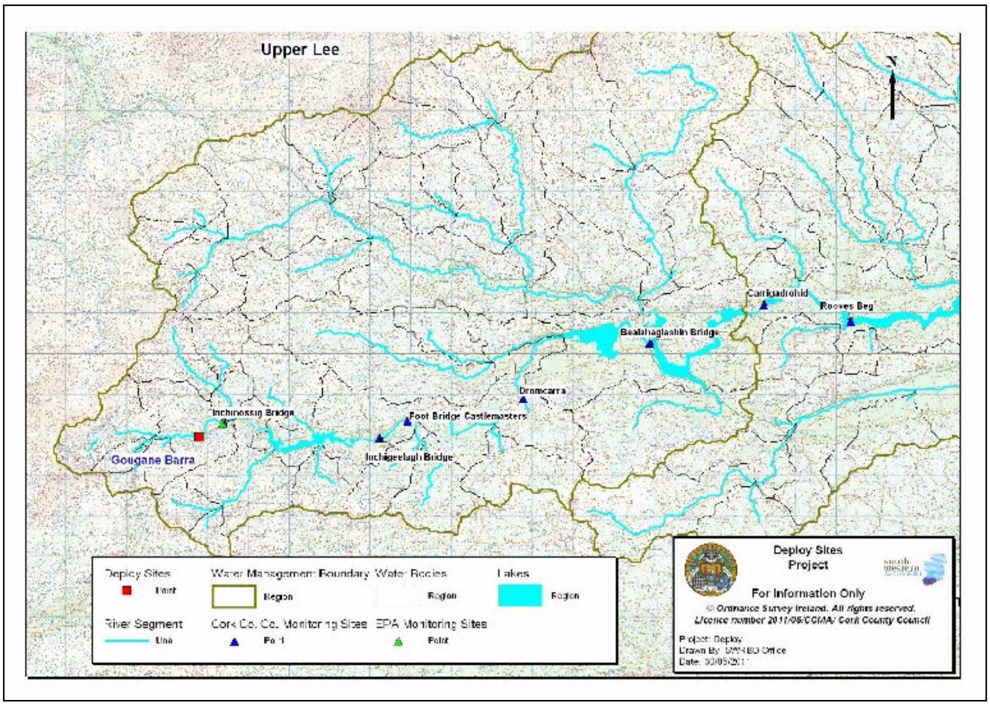

Figure 5.8. Overview of the monitoring stations operated by the EPA (green marker) and Cork County Council (blue markers) in the upper Lee Catchment close to the DEPLOY station at Gougane Barra (red marker).

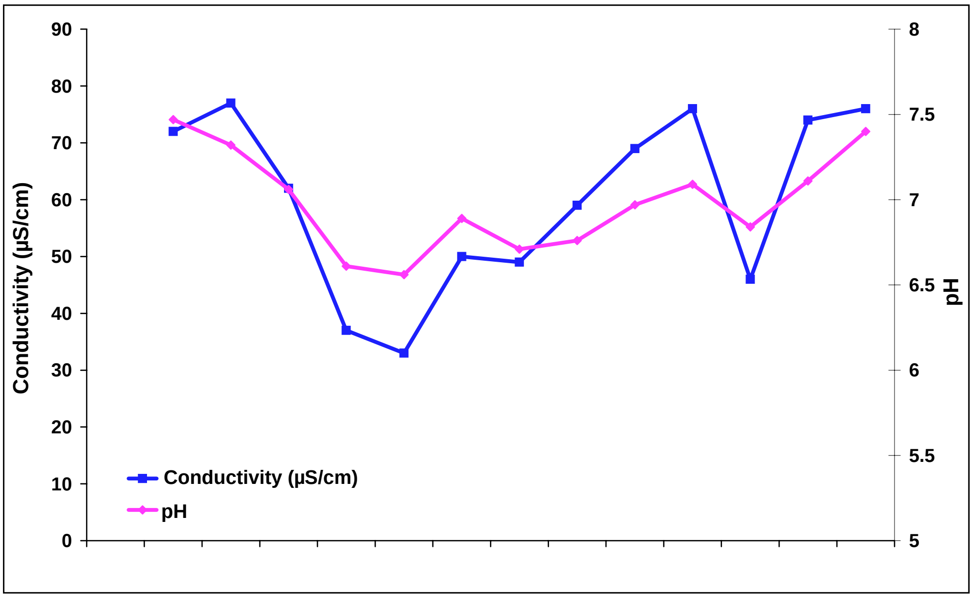

Figure 5.9. Monthly conductivity (µS/cm) and pH grab sample concentrations over time (May 2009–May 2010) at the EPA's Inchinossig Bridge site in the upper Lee Catchment.

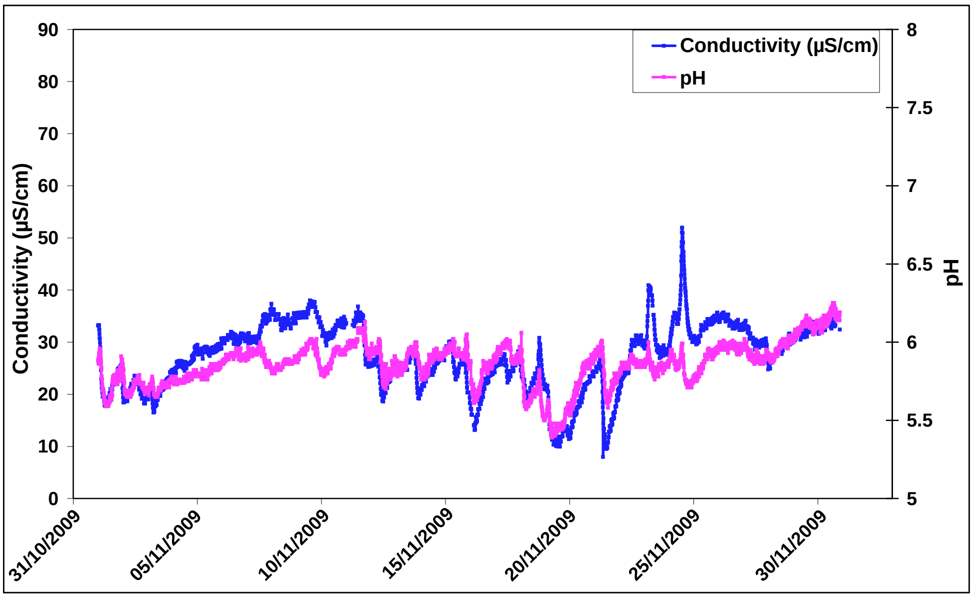

Figure 5.10. One month's readings (November 2009), samples taken every 10 min for conductivity (µS/cm) and pH from the DEPLOY station at Gougane Barra.

showing clear diurnal fluctuations, which vary with ambient meteorological conditions, can be seen.

Rapid changes in both pH and conductivity were observed over short periods at the Gougane Barra station over the course of the deployment. These sudden fluctuations are likely to have been caused by run-off from the steep topography and surrounding peatlands upstream of the Gougane Barra site and corresponded to higher than average rainfall over the previous 24-h period. The relatively shallow fast flow at the site keeps the water well oxygenated and it is understood that there is limited nutrient loading. Five Met Éireann rainfall stations (Fig. 5.11) taking average daily rainfall are located within an 8-km radius of the DEPLOY site at Gougane Barra; however, most of

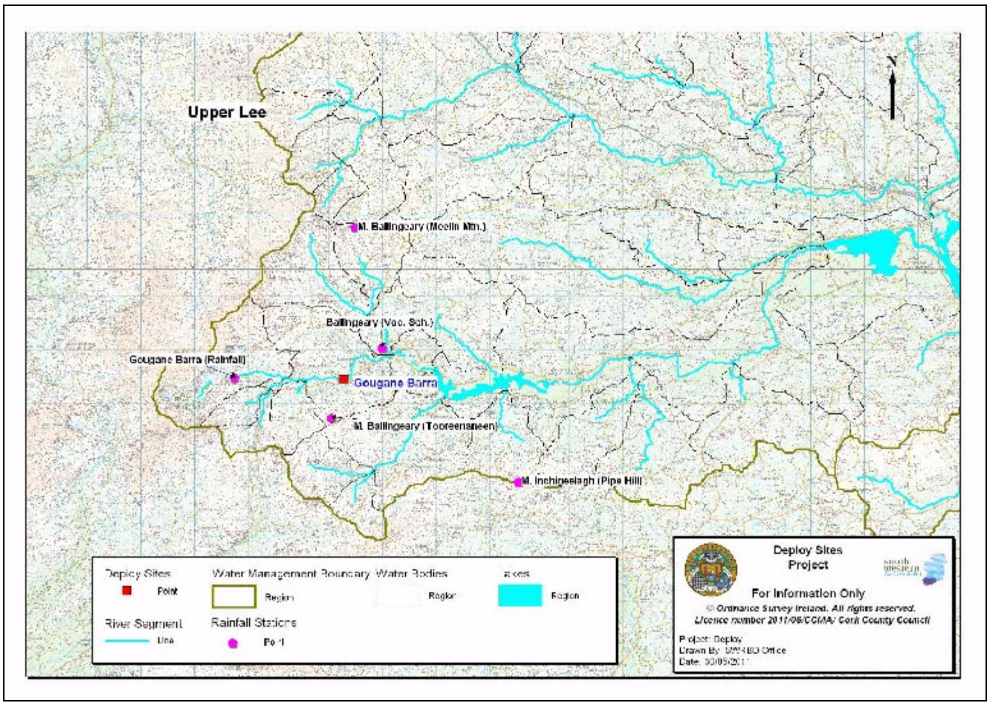

Figure 5.11. Met Éireann rainfall stations located within a 8-km radius of the DEPLOY station at Gougane Barra (red marker).

these stations appear to be no longer in use and for the period of the DEPLOY project limited rainfall data were only available from one station, Ballingeary (VOC.SCH).

November 2009 is notable for the high rainfall recorded and the consequent severe flooding experienced in many parts of the country. Rainfall totals recorded by Met Éireann for November 2009 were the highest on record at most stations, with more than twice the average November rainfall measured at the rainfall station, Ballingeary (VOC.SCH) located in the upper Lee Catchment (see Table 5.3). The most extreme rainfall occurred on 18–19 November. This led to severe flooding in many areas, but especially the Lee Catchment (Walsh, 2010). As can be seen from Fig. 5.10, the adverse weather conditions did not affect the system performance at the Gougane Barra station and data were logged without interruption, which enabled a greater understanding of some of the processes occurring at the site during these extreme weather conditions.

A maintenance visit occurred on 11 November 2009. Sensors were inspected and cleaned, and readings

Table 5.3. A comparison 30-year rainfall averages (mm) and current available rainfall data from Met Éireann Ballingeary (VOC.SCH) rainfall station from the period of deployment, May 2009–May 2010.

	Average mm of rainfall at Ballingeary (VOC.SCH)	
	1961–1990	**2009–2010**
May	115	126.5
June	87	111.6
July	85	219.9
August	122	263.6
September	150	
October	206	
November	202	**484.8**
December	240	
January	256	
February	191	
March	176	
April	107	
Total	**1,937**	

were taken with the calibrated YSI© ProPlus hand-held instrument as close as possible to the in-situ sensors and within 1-min intervals (see Fig. 5.12). All information relating to the maintenance visit and sensor inspection was recorded in a field notebook so any potential anomalies with the data could be checked at a later date.

Table 5.4 displays a comparison of the DEPLOY system and the YSI© ProPlus hand-held sensor recorded values of conductivity (µS/cm), pH and temperature (°C) at Gougane Barra on 11 November 2009. While the YSI© ProPlus was not used for calibration purposes, the hand-held meter readings provide a sense of the value of the in-situ data

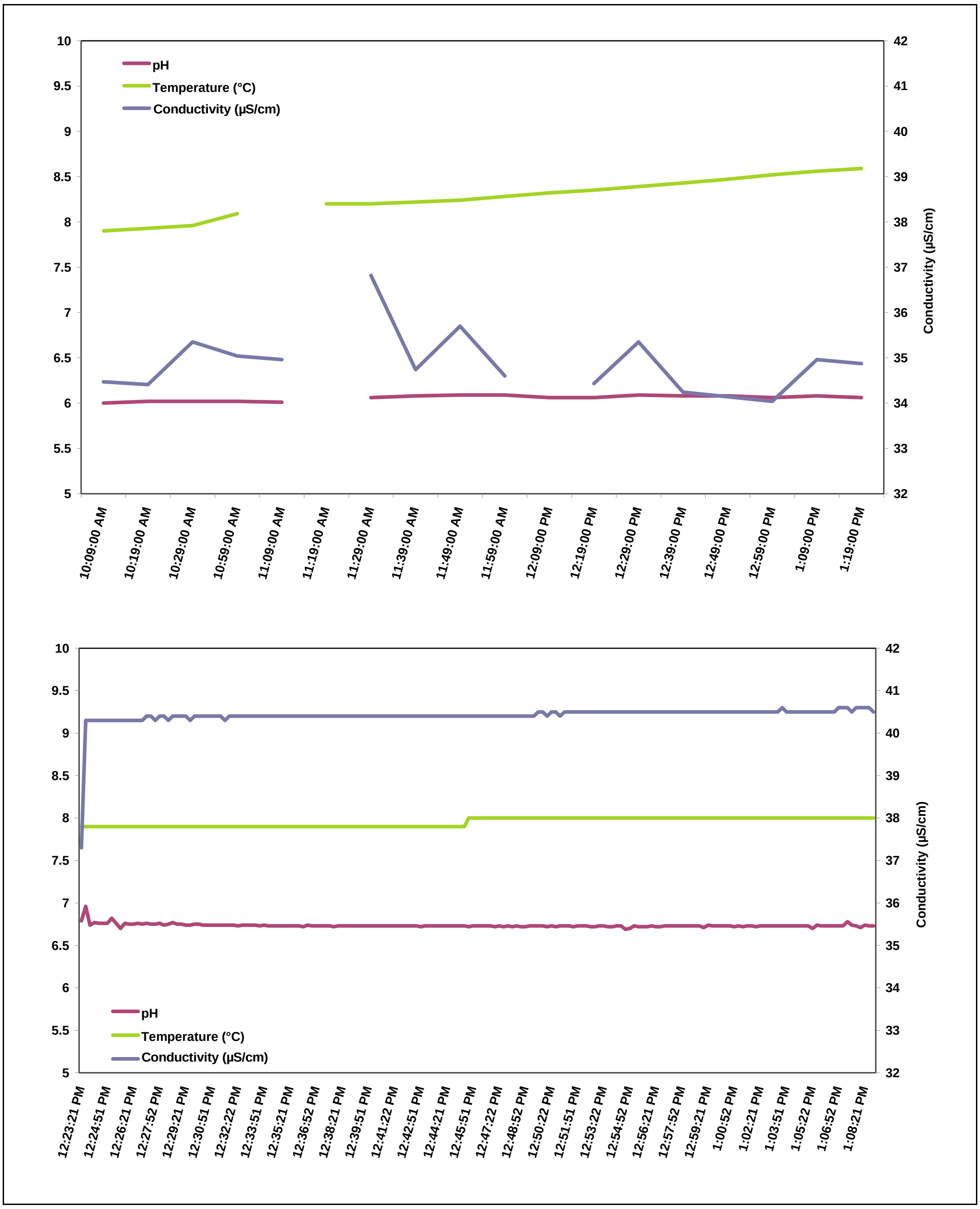

Figure 5.12. Comparison of conductivity (µS/cm) (secondary axis), pH and temperature (°C) (primary axis) collected by the DEPLOY system (top) and the YSI© ProPlus (bottom) over a comparable time on maintenance visit 12 (11 November 2009) at Gougane Barra.

Table 5.4. Mean (±SE), range and sample size (*n*) of measures of conductivity (µS/cm), pH and temperature (°C) at Gougane Barra on 11 November 2009, maintenance visit 12. Comparison of the DEPLOY system and the YSI© ProPlus hand-held sensor taken over an overlapping time period at different sampling interval rates.

	Gougane Barra (DEPLOY)	Gougane Barra (YSI© ProPlus)
Conductivity (µS/cm)		
Mean ± SE	34.88 ± 0.19	40.42 ± 0.02
Range	34.04–36.82	37.3–40.6
n	15	183
pH		
Mean ± SE	6.06 ± 0.01	6.73 ± 0.0
Range	6.0–6.09	6.69–6.96
n	16	183
Temperature (°C)		
Mean ± SE	8.25 ± 0.05	7.95 ± 0.0
Range	7.9–8.56	7.9–8.0
n	16	183

recorded and the level of potential fouling and drift. The table shows that all data recorded by the two systems were within an acceptable range.

5.3.2 Inniscarra Databuoy

This Inniscarra Databuoy station was not as routinely maintained as the other four stations in the DEPLOY project. This was owing to the fact that the sensors were deployed on a buoy that required the use of a boat for access. Public boat access to the reservoir is restricted and the availability of suitable hire boats is limited.

Data collected from the station showed the difference in dissolved oxygen (mg/l) and temperature (°C) between the two depths (see Fig. 5.13). Observed fluctuations of dissolved oxygen and temperature at a depth of 6 m were independent from readings observed at the surface. It is thought that, owing to the steep contours of the flooded valley at Inniscarra, underwater currents exist that are affected by and increase with the opening of the hydroelectric dam downstream. In normal day-to-day operations, the dam at Inniscarra is operated to maximise electricity generation, which varies with daily demand. The rate of electricity generation is dependent on the available head of water, which varies seasonally and is controlled by the reservoir at Inniscarra and upstream at Carrigadrohid, and flow rate.

In June 2009, a problem was identified with the databuoy’s charge regulator located on the solar panels, which was overcharging the battery packs and supplying the instruments with a voltage that was too high during certain parts of the day. Once the problem was identified, an additional power regulator was introduced and the system functioned properly.

In January 2010, extreme weather conditions in the Lee Catchment caused the Inniscarra Reservoir to freeze and the databuoy became embedded in the surface ice sheet. Figure 5.14 shows a swan walking on the ice sheet surrounding the databuoy. As the ice melted, the combination of strong easterly winds and slow river flow at the site pushed the breaking ice sheet upstream against the current and dragged the databuoy more than 1 km upstream to a new near-shore site. The databuoy remained at this location for the remaining part of the project.

5.3.3 Inniscarra Pumphouse

The Inniscarra Pumphouse station is located at the intake tower for the Inniscarra Waterworks. The

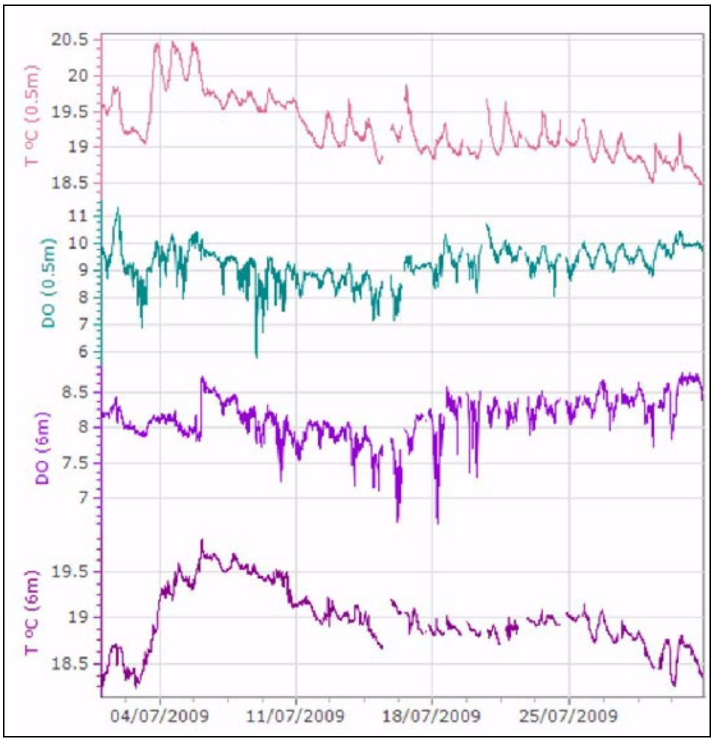

Figure 5.13. Observed fluctuations in dissolved oxygen (mg/l) and temperature (°C) at 0.5 m (top) and 6 m (bottom) depths over 1 month (July 2009) at the Inniscarra Databuoy station.

Figure 5.14. Swan walking on a frozen Inniscarra Reservoir close to the Inniscarra Databuoy station, January 2010.

instruments are located in a constant-flow steel tank pumping water from a depth of 5 m.

Local factors, such as the geology, influenced the measured parameters and the fouling rate of the instruments. The valleys around the reservoir are underlain by carboniferous limestone hemmed in by ridges of Devonian sandstones and conglomerates. This underlying geology results in increased iron and manganese concentrations, owing to the dissolution of iron and manganese, which are contributors to water hardness from the sandstone where reducing conditions occur. The concentration of manganese varies seasonally, and contributes to sensor fouling, which is visually more evident during the winter and spring (Fig. 5.15). Bio- and geofouling are major problems that occur when any type of sensor is immersed in water. Bacterial growth or sediment

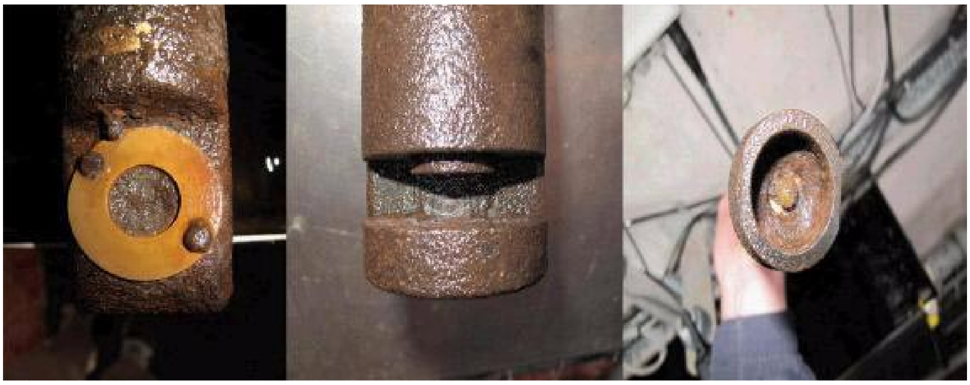

Figure 5.15. Fouled sensors at the Inniscarra Pumphouse station prior to cleaning, March 2010.

deposits on the instrument can lead to changes in the recorded variables. As there is no general model to predict the level or rate of fouling, it has to be assessed locally.

The closest monitoring stations upstream and downstream of the two DEPLOY stations at Inniscarra are Cork County Council sites at Rooves Beg (8.4 km) and Inniscarra (4 km) (Fig. 5.16).

A comparison of the data collected from the DEPLOY Inniscarra Pumphouse station with Cork County Council stations at Carrigadrohid and Inniscarra, as well as grab samples collected at the time of DEPLOY maintenance visits, shows that the average data readings across stations are within acceptable ranges (Table 5.5). However, it can be seen that the timing of data collection when taking spot/grab samples is important as events may be missed, with low minimum temperature values recorded by the DEPLOY system during extreme weather over the 2009–2010 winter.

Over the course of the deployment there was an issue with the pump used in the flow-through system at this

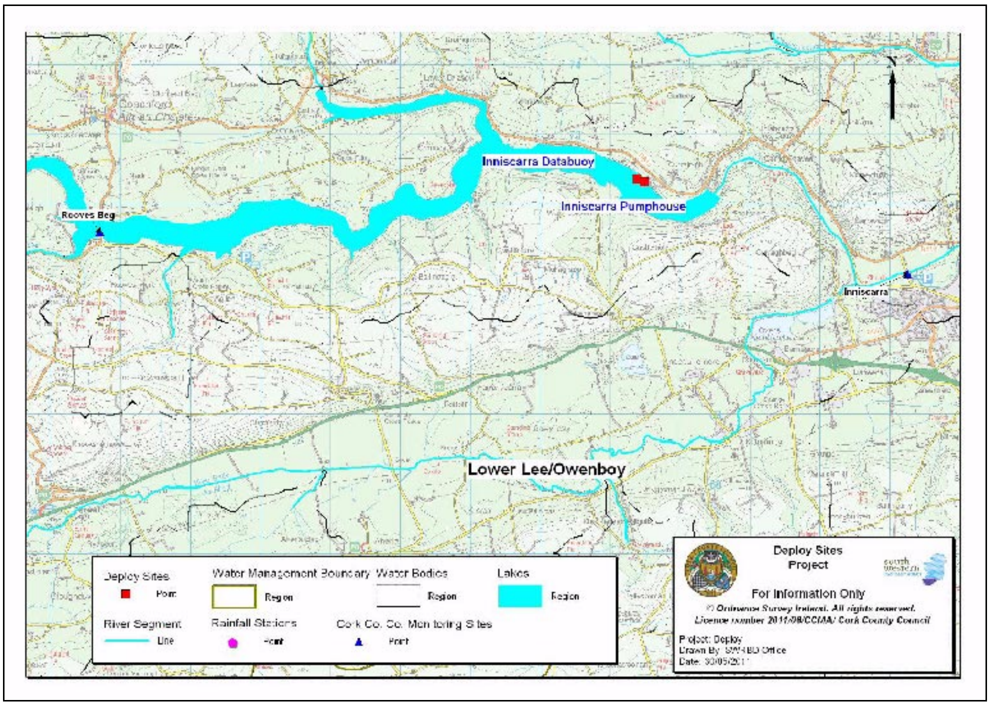

Figure 5.16. Overview of DEPLOY stations on Inniscarra Reservoir (red marker) and Cork County Council operational monitoring sites at Carrigadrohid and Inniscarra (blue marker).

Table 5.5. Mean (±SE), range and sample size (*n*) of measures of DISSOLVED oxygen (mg/l), pH, Conductivity (µS/cm) and TEMPERATURE (°C) at Inniscarra Pumphouse and surrounding stations (May 2009–May 2010).

	Carrigadrohid (Cork County Council)	Inniscarra (Cork County Council)	Inniscarra pumphouse (DEPLOY)	Inniscarra pumphouse (laboratory analysis)
Dissolved oxygen (mg/l)				
Mean ± SE	9.08 ± 0.61	9.62 ± 0.57	9.91 ± 0.01	9.26 ± 0.31
Range	6.9–11.8	7.1–12.0	6.26–12.8	8.43–12.23
n	10	9	54,631	12
pH				
Mean ± SE	7.44 ± 0.06	7.63 ± 0.07	7.4 ± 0.0	
Range	7.0–7.7	7.4–7.9	5.19–8.75	
n	10	8	55,221	
Conductivity (µS/cm)				
Mean ± SE	107.11 ± 5.09	144.11 ± 6.9	94.85 ± 0.1	
Range	83–128	117–176	65.57–142.9	
n	9	9	20,831	
Temperature (°C)				
Mean ± SE	11.98 ± 1.32	13.49 ± 0.94	12.0 ± 0.02	15.46 ± 1.02
Range	5.1–18.8	9.7–16.5	1.97–20.16	8.4–19.5
n	10	8	54,800	11

site. The pump failed several times, meaning that the sensors were sampling stagnant water. When a new pump was installed at the site, it was found to be lacking power and this resulted in a reduced flow through the tank. This reduction in flow had a knock-on effect on collected values over the period the pump was in place. Flow was restored when the new pump was installed. The Chelsea Technologies MINITracka chlorophyll-*a* sensor present in the flow-through tank malfunctioned during the reporting period. Increased chlorophyll-*a* found during routine maintenance visits and confirmed through Cork County Council's own routine reporting was not replicated in data collected by the sensor.

5.3.4 Lee Road

The Lee Road site is located close to the intake for the Lee Road Waterworks in Cork City. It is the first site located downstream of the dam at Inniscarra and is just upstream of the weir signifying the end of the freshwater system and the beginning of the saline-influenced system. An advantage of this station is its proximity to the Lee Road Waterworks intake point on the river bank, with significant flow from the main channel displaying fluctuations in physico-chemical parameters.

From the data collected in DEPLOY, it was observed that the release of water from the hydroelectric dam upstream at Inniscarra has an immediate effect on observed physico-chemical parameters at the site. This demonstrates the benefits of high frequency monitoring, with data available in real time. Figure 5.17 displays depth (mm) and conductivity (µS/cm) at the Lee Road over a 1-week period in May 2009. The release of water from the dam upstream caused an increase in water level of ~300 mm over a short period. This fresh water had a corresponding effect on conductivity as the additional discharge and flow had the effect of reducing the conductivity over the period of the discharge.

The length, timing and seasonal effect of the release of this water to generate electricity may have an effect on water quality downstream of the dam. Figure 5.18 displays depth (mm), chlorophyll-*a* (µg/l) and pH over 1 week in June 2009. The release of water from the

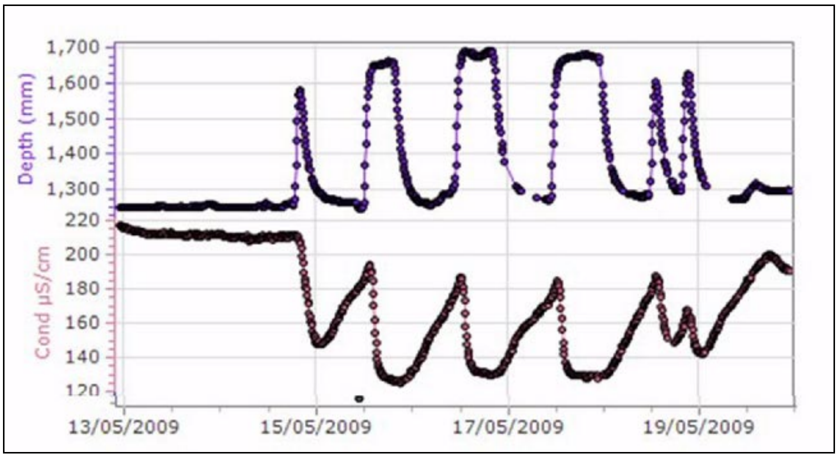

Figure 5.17. Depth (mm) and conductivity (µS/cm) readings from the Lee Road station over a 1-week period in May 2009.

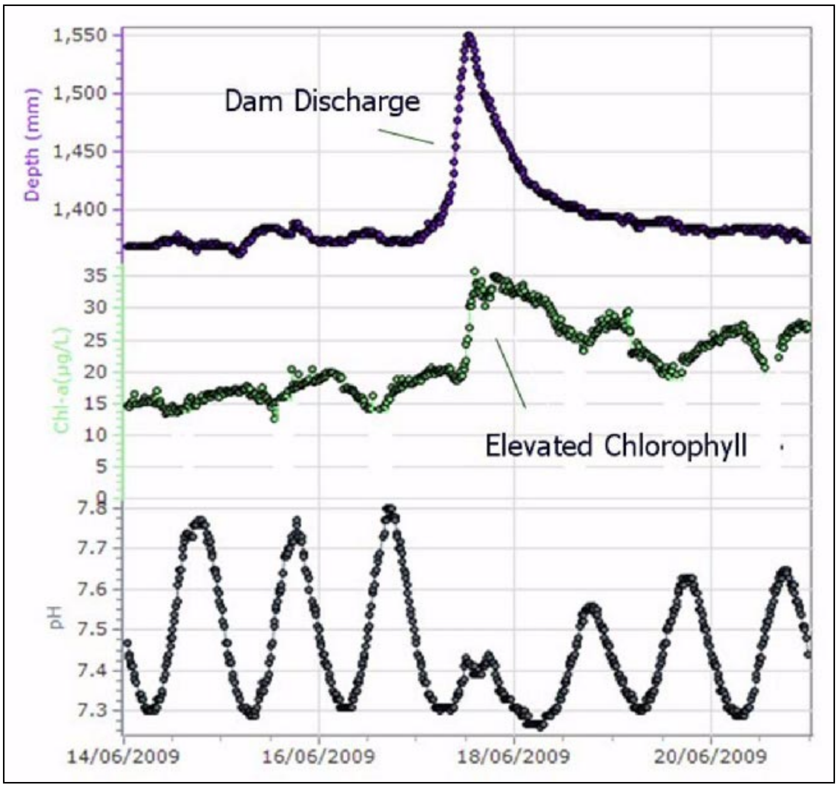

Figure 5.18. Fluctuations in depth (mm), chlorophyll-*a* (µg/l) and pH over 1 week in June 2009 at the Lee Road station.

dam at this time corresponds with increased chlorophyll-*a* readings, which could have been caused by the increased flow disturbing plant biomass on the river bed or planktonic algae present in the reservoir being carried along with discharged water released by the dam.

These short-term events identified by the DEPLOY project data demonstrate how the information derived from the system could be used as a decision-support tool in managing the catchment. Some of the organisations whose discharges may affect or be affected by water quality at this section of the River Lee include the ESB, the Council's wastewater treatment plant at Ballincollig and the waterworks at the Lee Road, which provide drinking water to areas of Cork City. The availability of access to real-time data would enable managers to monitor the impact of their decisions and then take appropriate action. Recognising the importance of monitoring the temporal and spatial variations in waterbodies, the DEPLOY system allows users to compare parameters measured in real time from different stations.

Figure 5.19 displays a comparison of parameters (pH and temperature) measured in real time at three DEPLOY stations in November 2009. The stations are Gougane Barra (blue) near the river source, Inniscarra Pumphouse (green) in mid-river and the Lee Road station (red), which, as mentioned above, is just before the river becomes estuarine.

The pH of most natural waters is between 6.0 and 8.5, although lower values can occur in dilute waters that have a high organic content. The upper graph in Fig. 5.19 shows a difference in pH recorded at Gougane Barra compared with the other stations located further downstream. Gougane Barra is surrounded by peatlands and run-off and flow at this time may have caused the lower pH reading recorded. Changes in pH can indicate the presence of certain material, particularly when continuously measured and recorded; together with the conductivity during flooding experienced on 19–21 November, spikes in pH were observed at the height of the flood event at the Lee Road site showing the value of real-time monitoring. The grey enclosure shown in Fig. 5.20, which housed some of the station's components, became partially submerged; however, the ruggedised nature of the system meant that the sensors continued to transmit data despite the conditions being experienced.

Figure 5.19. Comparison of parameters (pH in the upper graph and temperature in the lower graph) measured at three DEPLOY stations in November 2009. The stations are Gougane Barra (blue), Inniscarra Pumphouse (green) and the Lee Road station (red).

Figure 5.20. Lee Road site during normal conditions (left) and elevated water levels experienced during flooding in November 2009 (right).

In early June 2009 at the Lee Road station, some of the instruments performed poorly. A problem was identified relating to slow telemetry and spiking of the EC3000 data. Modifications were made to the power system and to the POD software and the EC3000 was replaced with an EC250, thereby resolving the problem. Two problems were identified with the Chelsea© Technologies TriLux sensor at this station (discussed earlier in Section 5.1). The instrument was found to be extremely sensitive to fouling and in sunny weather suffered from ambient light contamination. This contamination was evident in the TriLux data and was seen as intermittent negative spiking. While efforts to resolve these TriLux issues were made, the project budget did not permit the implementation of an automatic antifouling solution such as a wiper. Efforts by Chelsea© Technologies to resolve the ambient light issue have resulted in the development and provision of an ambient light shield for use in shallow water applications.

5.3.5 Lee Maltings

Owing to the tidal nature of this site a pumped solution was implemented. The water sample was pumped from the river bed every 10 min and discharged into a tank on the quay side. Initially this set-up worked well; however, over time, persistent fouling and regular seasonal blockage of the filter at the pump intake and the flow-through tank caused a gradual deterioration in the collected data (Fig. 5.21).

It was found that when the water level at the site was low, access to the filter intake was possible at low tide, enabling the problem to be easily resolved by cleaning the filter. However, owing to inclement weather conditions during the summer and autumn of 2009 and the combination of effects owing to tides and dam releases from Inniscarra at certain times, access to the filter intake location, even at low tide, was restricted, preventing or delaying certain maintenance activities. An additional large coarse filter was installed (Fig. 5.22) to alleviate the problem but while it extended the length of time before the filter gradually clogged it did not eliminate the issue.

From the experiences in DEPLOY it can be concluded that if a similar station were required or the Lee Maltings station were to be maintained in the long term, an arrangement that would enable the filter to be cleaned by backwashing should be implemented.

Figure 5.23 shows the typical graphical output over a 5-day period in early July 2009 from the tidally influenced Lee Maltings site, with readings (top to bottom) of chlorophyll-*a* (µg/l), dissolved oxygen (ppm), dissolved oxygen (% sat.), temperature (°C), conductivity (mS/cm) and depth (m) recorded every 10 min. The normal changes arising owing to tidal changes at the site resulted in a rapid change from saline to fresh water, corresponding with fluctuations in depth and conductivity. Increased dissolved oxygen concentrations and elevated temperature associated

Figure 5.21. Collection of images documenting fouling and the resulting blockage of the filter intake at the Lee Maltings station.

Figure 5.22. Coarse cage filter fitted to the sample filter inlet at the Lee Maltings.

with the ebbing tide and spikes in chlorophyll-*a*, visible at high tide, were also observed. The low levels of dissolved oxygen observed at this time provide evidence of tidal hypoxia at the site, which can develop in stratified water caused by the advection of poorly oxygenated water from further downstream and better oxygenated fresh water from upstream. After the addition of the coarse cage filter, the filter intake was raised approximately 30–40 cm off the river bed and low dissolved oxygen levels (<4 mg/l) were less frequently observed.

The release of water from the hydroelectric dam upstream at Inniscarra had a significant impact on measured physico-chemical parameters at the Lee Maltings site. Figure 5.24 shows a screen grab of a 4-day period in early August 2009 showing (top to

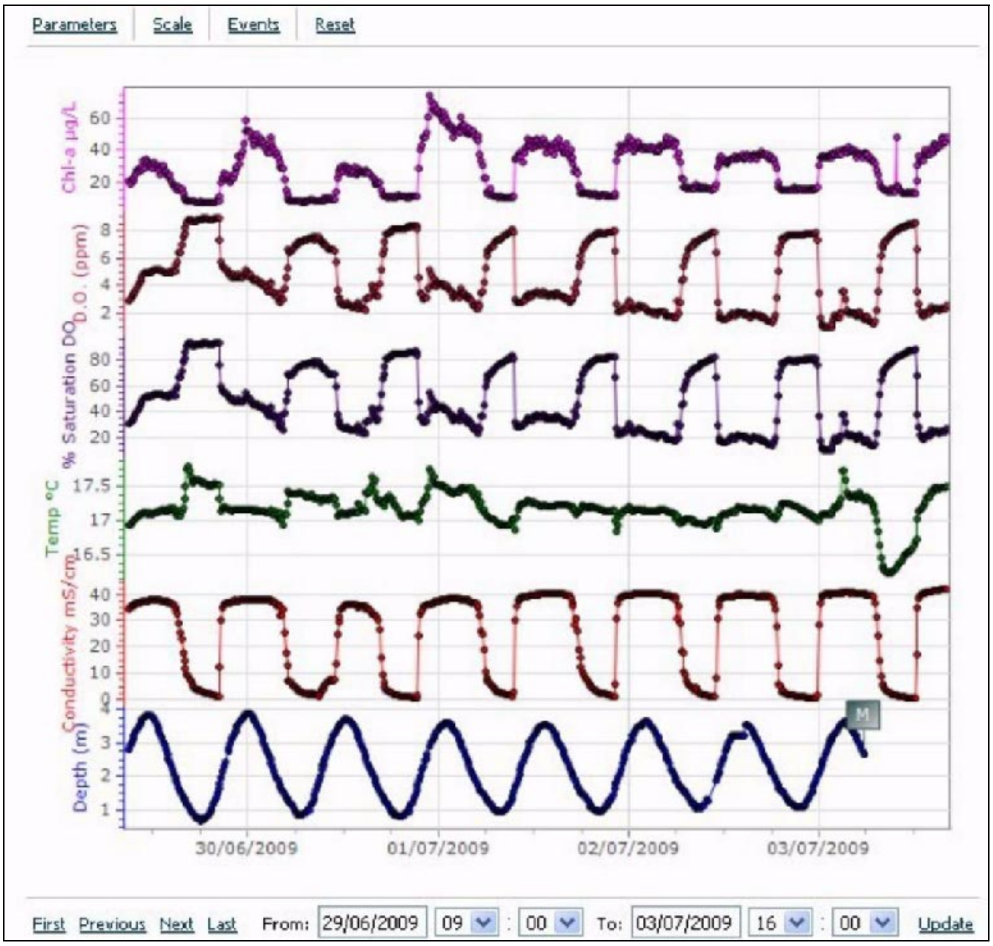

Figure 5.23. Typical screen grab (taken from the DEPLOY website) of a 5-day period in early July 2009 showing (top to bottom) chlorophyll-*a* (µg/l), dissolved oxygen (ppm), dissolved oxygen (% sat.), temperature (°C), conductivity (mS/cm) and depth (m) recorded every 10 min at the Lee Maltings.

bottom) chlorophyll-*a* (µg/l), dissolved oxygen (ppm), dissolved oxygen (% sat.), temperature (°C), conductivity (mS/cm) and depth (m) recorded every 10 min.

The screen grab shown in Fig. 5.24 differs from that in Fig. 5.23 in that at high tide, salt water (elevated conductivity levels) is absent at certain tidal cycles. The reason for this is the release of a large volume of fresh water from Inniscarra dam upstream forcing the salt wedge out at the site. This more oxygenated fresh water (depending on the season and retention time in the reservoir prior to release) has an effect on temperature, dissolved oxygen and chlorophyll-*a* levels at the site. The short-term changes observed and the combinatorial effects of the dam and tide at this site are only clarified through the use of real-time high-intensity data collection as seen in the DEPLOY data.

At the Lee Maltings site, maintenance was required the day after the major flood event in Cork City on 19 November 2009. Figure 5.25 shows the typical water level at the site at low tide and the water level on 20 November 2009, the day after peak flow.

The DEPLOY system at the Lee Maltings had been configured to be mains powered. The flooding event of November 2009 caused power outages across Cork City. For health and safety reasons and in order to protect sensitive equipment, the Tyndall Institute initiated a controlled power shutdown at the site. As a consequence, the data collection was stopped at this site and the peak flood event was missed. To prevent this power outage effect occurring again, the system was reconfigured and a back-up battery was installed to ensure continuity of data in case an event of this kind reoccurring.

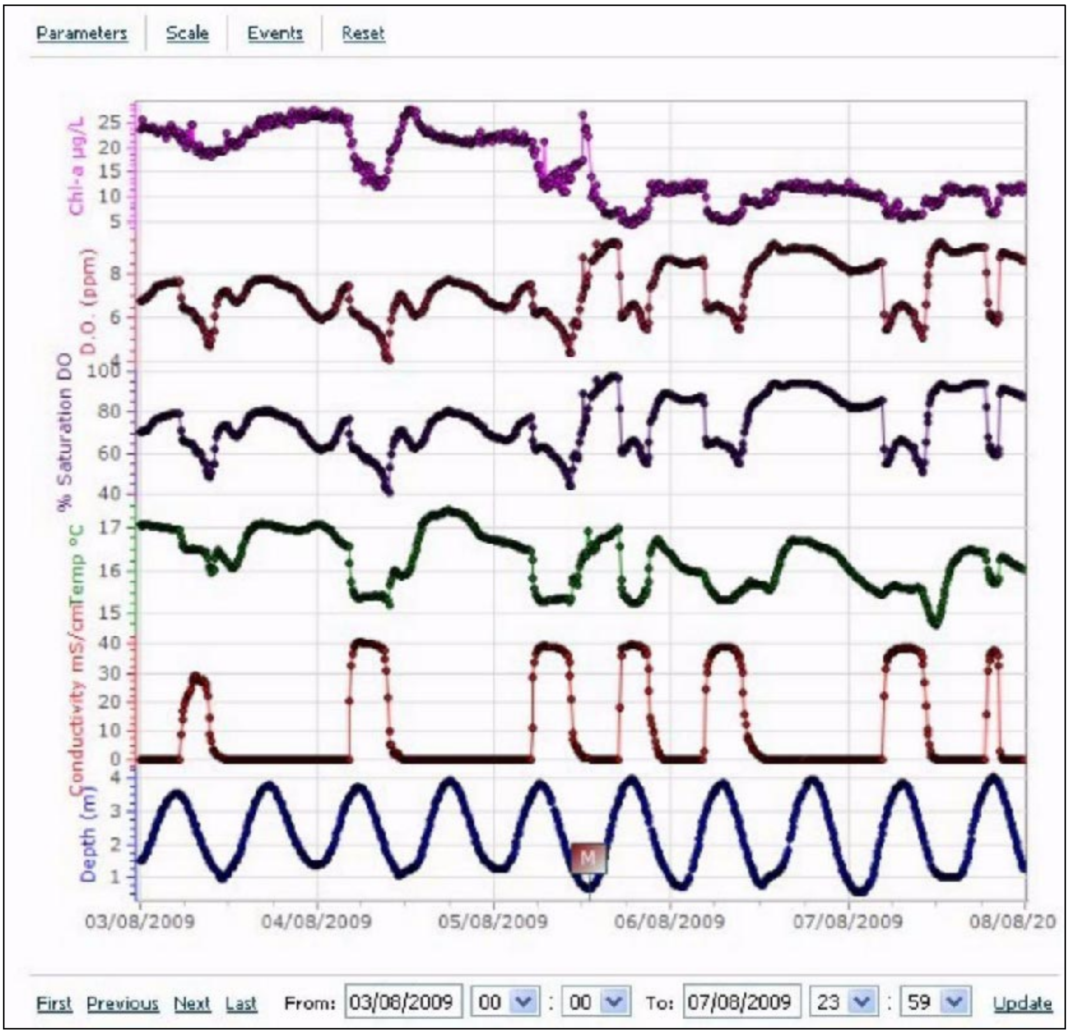

Figure 5.24. Typical screen grab of a 4-day period in early August 2009 showing (top to bottom) chlorophyll-*a* (µg/l), dissolved oxygen (ppm), dissolved oxygen (% sat.), temperature (°C), conductivity (mS/cm) and depth (m) recorded every 10 min at the Lee Maltings.

Figure 5.25. Typical water level at low tide (left) and after flooding in November 2009 (right) at the Lee Maltings.

6 Conclusions and Recommendations Arising from DEPLOY

6.1 The Need

Environmental monitoring is key to measuring and understanding the chemical and biological quality of water and for taking action as required. Over the coming years, monitoring of waterbodies will increase within Europe in order to comply with the requirements of the WFD. The establishment of long-term monitoring programmes is regarded as essential if the implementation of the WFD is to be effective. We now have opportunities to sense and analyse the environment around us. Technological advances are providing new sensor capabilities, novel network capabilities, long-range communications technologies and data interpreting and delivery formats via the world wide web. However, while measurement and detection of environmental pollutants can be successful under laboratory-controlled conditions, continuous in-situ monitoring remains a challenging aspect of environmental sensing.

6.2 The Ideal System

Laboratory analysis is still the norm for the majority of parameters of environmental interest but, in the rapidly developing field of environmental monitoring, there is much published research in the area of sensor development. The ideal monitoring system consists of a network of sensors deployed at key locations, capable of autonomous operation in the field for a long period of time. The data from the monitoring system are communicated by wireless technology for processing and interpretation. Many elements of the ideal system are in place, but ongoing research and development is required in several areas relating to sensor development, testing and validation. In addition to basic water quality parameters, such as dissolved oxygen, conductivity and pH, future developments in in-situ nutrient analysis will also ensure that these key water quality parameters are routinely and reliably measured in the environment. Moreover, toxicity monitoring will be used as a screening tool, albeit non-specific, for detecting the advent of unsatisfactory water quality.

Currently, laboratory-based instruments are capable of high accuracy, selectivity, stability and sensitivity but suffer from high cost and high power requirements. The ability to make accurate, continuous, long-term measurements in the environment is restricted by a number of interdependent factors, notably:

- Accuracy;
- Selectivity;
- Sensitivity;
- Temporal stability;
- Data transmission;
- Sampling;
- Power requirements;
- Temporal and spatial coverage;
- Robustness; and
- Cost.

At the other end of the scale, simple dipstick sensors can suffer from poor selectivity, accuracy, and sensitivity, but are cheap enough that they can be deployed over a wide area and used in situ.

Progress has been made in the development of in-situ nutrient-sensing devices, based on fluidic systems, which are capable of autonomous continuous operation over extended periods of time. However, these require replenishment of reagents, and have significant power requirements for pumps. etc. In order to develop automated sensors for water quality monitoring, there is a need for the development of chemical and physical sensor technologies tailored to the specific requirements of this type of analysis, with the capability for networking and wireless data communication.

6.3 Recommendations Arising from DEPLOY

From the 12-month deployment, a number of key general recommendations can be provided. These recommendations may serve to assist in the development and the application of future sensor-based monitoring systems. The standard approach today is spot sampling and laboratory analysis. Continuous monitoring using sensors and sensor networks is not competing with existing monitoring programmes but will be complementary to them and provide added value.

In earlier chapters, a variety of snapshots of data have illustrated the real value of collecting data in real time at high frequency. The benefit of a thorough maintenance schedule was clear from the quality of the data collected and the percentage data points retrieved (96%) for the 12-month period.

The Lee Catchment was a particularly challenging one to use in demonstrating the value of a continuous monitoring system. The catchment running from Gougane Barra to the Lee Maltings sees variation in water flow, land use, geology, water use and tidal influence. However, the variety of environmental factors in the catchment and weather conditions in the period under study provided a range of scenarios that could be evaluated to assess the system performance – to the benefit of the study. Owing to the scale of the catchment, the deployment would have gained benefit from a scoping study to assess the site-specific conditions that impact on a deployment of such a scale. Such a study would also have shown the need for a greater number of sites in order to get greater value from the deployment in terms of environmental observations.

The clear benefits of such a system lie in its ability to support a monitoring programme. It is possible to locate sensor systems in high-risk sites and in remote areas to aid small-scale studies with county councils. The scale and make-up of a particular monitoring system will depend on the needs of the particular user (agency, industry, local authority, etc.). The system can be simple or more sophisticated depending on the needs.

A range of scenarios for use of such a simple monitoring system might include:

- Remote, difficult-to-access sites of high risk;
- In-situ nutrient analysis;
- Depth monitoring at a range of sites liable to flooding;
- Conductivity and turbidity sensors providing good indications of water quality change;
- pH used in sites liable to flooding and run-off to support depth measurements;
- Dissolved oxygen and temperature readings which are of value to the aquaculture industry;
- Temperature and conductivity or turbidity readings which can be used in areas of tidal influence to support decisions relating to algal blooms; and
- Temperature and chlorophyll-*a* readings providing real-time data on algal presence in a system.

From the experiences gained in DEPLOY, a number of recommendations can be given. A costing of a monitoring system is not reliable as the system deployed will depend on site conditions and each site will have different sensor as well as engineering/infrastructure requirements.

6.3.1 Site selection

Because a scoping study was not carried out prior to DEPLOY, sites were selected based on ease of access, access to power, communications availability and infrastructure as well as environmental interest. From the deployment, it is clear that when planning a monitoring system for a waterbody it is necessary to select sites that:

- Represent that waterbody;
- Can be accessed safely during all weather conditions and at suitable times of the day;

- Have suitable wired or wireless communication options, as well as options for sensor platforms and housings; and
- Consider power availability.

A scoping and reconnaissance survey of the catchment or sites prior to finalising the sensor location is recommended. Site-specific issues must be accounted for. The issue of vandalism and system loss due to environmental factors must be considered and, thus, a sustained infrastructure must be considered a site-specific issue.

6.3.2 Sensor type and selection

Selection of sensors for water quality parameters will depend on the need of the user. In the DEPLOY project, the project team chose a selection of sensors that regulatory agencies commonly use. The DEPLOY system was configured such that other freely available commercial sensors (to meet the chemical and physico-chemical elements required by the WFD) could be incorporated into the system. However, at some sites only very routine measurements may be necessary (conductivity, pH, temperature, turbidity) and, with adequate spatial and temporal frequency, these measurements can provide a valuable picture of water quality, as was the experience of DEPLOY. In other cases, more sophisticated sensors such as chlorophyll-*a*, nutrients, bacteriological measurements (when available) will be necessary – these will be a more costly choices in terms of purchase and maintenance and will be used only at certain sites. It will not be necessary to have every site fitted with every sensor with high frequency data collection. The system must match the user need and this can be evaluated before the system is put in place. The recommendation is to treat every site individually having carried out a scoping study to evaluate the local environmental conditions. This will assist in determining what sensors should be selected.

6.3.3 Sensor maintenance and validation

It is clear that one of the major challenges for any DEPLOY-type implementation is the maintenance of the sensors. From the experience gained, it is clear that greatest maintenance is required during spring and summer months, with a lesser requirement in cooler and darker months. There are technologies emerging that can be used to keep sensors clean between measurements, but some of these are expensive, power hungry in many cases and not suited to all sensor systems. There is a need to further develop anti-biofouling and anti-geofouling technologies with the objective of deploying systems that only require maintenance every month rather than every fortnight for example, that would provide significant reduction in maintenance costs or ideally reduce maintenance to once every 6 months. This requirement may involve work in sensor design, antifouling materials, mechanical systems and fouling detection.

While sensors provide very valuable data and information in real time, it is necessary to validate systems for a period of months so that the quality of sensor data may be assessed. This must be done by normal grab sampling methods for each parameter and using hand-held meters for on-site correlation of data at the time of sample collection is also recommended.

6.3.4 Platform design and sensor ruggedisation

The sensor housing needs to be rugged and waterproof to withstand the extremes of environmental conditions experienced by such sensing systems. The success of DEPLOY was emphasised in the capability of the system to withstand very severe weather conditions (flooding and freezing) in the winter of 2009. The stations deployed in this project were appropriate for the intended demonstration, and it is clear that for a long-term operational system the stations and their location require serious consideration. Failure to consider severe conditions when establishing a monitoring system may result in data failures and therefore a less valuable system.

6.3.5 Temporal and spatial frequency

The frequency of data collection requirements is a matter for the user. Some sites would benefit from high temporal (10 min) frequency while other waters may not need greater than multiple-hour frequency as they see less variability and are less vulnerable. Where monitoring systems are used for investigative or surveillance purposes, a higher temporal frequency would be desirable and adequate spatial frequency (adaptive) data collection is essential. This feature will determine the cost of the system as spatial frequency determines the number of individual sensing units needed.

6.3.6 Data collection

A highly reliable data management system should be used so as to enable constant access to the real time data being generated by the sensing system, as demonstrated in DEPLOY. In DEPLOY, data were processed in real time, filtered, archived and available to the user in a variety of formats, including mobile; data could be exported, merged/fused, data blogs were implemented, a metadata management facility was available, and users could set alarms. It is recommended that systems should be designed so as to enable future (and currently existing) data sources to be integrated in a seamless fashion.

6.3.7 Future needs

- While the potential of this technology is clear, the DEPLOY project also identified a number of gaps, particularly in the area of in-situ nutrient analysis. Further technological development in this area will be required if the goal of achieving a complete in-situ water quality monitoring solution is to be achieved.

- Investments are needed in a larger range of pilot studies to determine specific requirements and solutions for particular user requirements, for example for septic systems or sewage discharges. Providing incentives for companies to package sensing systems for use in particular tasks is an important step in making this technology accessible to the intended user base – environmental scientists and resource managers – and not just to computer scientists and electrical engineers. Pilot studies will be critical to providing the testing and specialisation required.

- Reference testing sites need to be developed for novel technologies and continuous validation procedures, which could be used by researchers, companies and agencies to test and validate technologies. Pilot deployments should be encouraged to test and refine data management tasks for specific applications. This includes sampling design, operation of the systems, and data analysis. Further work to improve system robustness and ensure high-quality data is needed.

- Environmental monitoring efforts also stand to benefit from additional focus on the integration of sensing systems with external data sources and third-party applications, especially map-based visualisation with tools for both rigorous Geographic Information System (GIS) techniques and more public friendly web applications.

- Professional development for the current environmental workforce is needed and can be achieved through direct training and facilitating partnerships between vendors, environmental science and engineering firms, and academia. Training at multiple levels is necessary to ensure that a ready workforce exists that is prepared to use these new sensing technologies.

- Support for undergraduate and graduate-level multidisciplinary programmes is crucial to expose students to the variety of disciplines that come together in these systems: computer science, electrical engineering, environmental engineering, and the biological sciences. It is important to ensure that the scale of a project is appropriate, especially when budget is considered.

- Development of integrated multi-parameter sensor systems that are robust, more sensitive and more reliable than traditional devices with the ability to be deployed for continuous remote monitoring using wireless communication in order to relay sensor information in real time. These sensor systems require advanced protective coatings comprising novel engineered nanocoatings in order to reduce biofouling. There is a need, therefore, for continued funding to support fundamental research to deal with biofouling and materials that can be used to counteract it.

- Innovative research into appropriate sensor technologies to enable inexpensive flow and pressure measurements as well as research and development into biological contamination, including the pathogens, nutrients and other water quality indicators.

- Collaboration between engineers and scientists is needed, with a view to specifying and promoting combined sensor and materials research and development, and transferring the technologies into industry. There is a need to fund fundamental research to improve and further develop new sensors, materials and communication systems. It is essential to scale-up new technologies so that they can be adequately tested before full-scale deployment.

6.4 Conclusions from DEPLOY

The DEPLOY project is a successful technology demonstration, showcasing how state-of-the-art technology can be used to achieve continuous, real-time monitoring of a river catchment. The project involved the collection of in-situ environmental data over a period of 12 months from a network of stations located in the River Lee Catchment, in County Cork. DEPLOY has demonstrated that this technology can be used to track fluctuations in a number of water quality parameters, such as temperature, dissolved oxygen and pH, across a catchment. This, in turn, has demonstrated the benefits of this approach over more traditional means of monitoring, which are likely to miss much of the temporal variability associated with these parameters. This technology demonstration of a truly heterogeneous water quality monitoring networked system is one of the first of its kind in Ireland and shows how data could be collected from a number of locations and viewed in real or near real time.

From the deployment, it was found that an important part of any water quality monitoring programme using sensors is the maintenance and validation of both the sensors and the collected data. Maintenance at certain sites during particular times of the year was required fortnightly owing to the effects of biofouling and/or geofouling, with local factors such as geology and meteorology influencing the measured parameters and the fouling rate. Efforts to reduce the impact of biofouling/geofouling on sensor data, in particular optical sensors, without the use of mechanical means requires further research.

The DEPLOY sensor data were compared with data collected in the field and data from the EPA and Cork County Council and it showed that DEPLOY sensor data readings across stations were within acceptable ranges. From the deployment, it was found that where issues with system or sensor performance arose they could be quickly and easily recognised and rectified using the alarm function on the DEPLOY website. The DEPLOY monitoring stations continued to function throughout the year in extreme weather conditions. The data were continuously collected and >90% data were recovered from the monitoring system at the five sites, with high temporal variance in parameters of interest observed over short periods at all sites. The sampling rate of 10–15 min used during the course of the deployment was found not to be necessary for all parameters measured at all sites. It was established that a longer time between sampling would reduce battery consumption and data cost in some cases.

While the potential of this technology is clear, the DEPLOY project also identified a number of gaps, particularly in the area of in-situ nutrient analysis. Further technological development in this area will be required if the goal of achieving a complete in-situ water quality monitoring solution is to be achieved.

The success of a monitoring system, such as DEPLOY, which can provide real-time data on a variety of water quality parameters over long periods of time, will rely on the support of teams of researchers in the development of the building blocks of the systems. There is a need for researchers across disciplines to work together to develop ‘Internet-scale sensing’ technology and to scale that technology up in order to validate its performance.

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Abbreviations and Glossary of Terms

BOD	Biochemical oxygen demand
DO	Dissolved oxygen
EC	European Community
EPA	Environmental Protection Agency
ESB	Electricity Supply Board
FTP	File Transfer Protocol
GIS	Geographic Information System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSI	Geological Survey of Ireland
GSM	Global System for Mobile
HMWB	Heavily modified waterbody
IP	Internet Protocol
ISM	Industrial Scientific and Medical
LAN	Local area network
LAs	Local authorities
LCD	Liquid crystal display
MI	Marine Institute
MOSFET	Metal oxide semiconductor field-effect transistor
NCSR	National Centre for Sensor Research
PSoC	Programmable System-on-Chip
QC	Quality control
RF	Radio frequency
SMS	Short Message Service
SN	Sensor Network
SWRBD	South Western River Basin District
TEDS	Transducer Electronic Datasheets
WFD	Water Framework Directive
WSN	Wireless Sensor Network

Appendix 1

Table A1. Parameters analysed by Cork County Council and the EPA at sites on the River Lee. Samples analysed by Cork County Council are taken monthly, while samples analysed by the EPA are taken every 3 months.

Parameters	Units
BOD	mg/l
pH	pH unit
Dissolved oxygen	mg/l
Conductivity	µS/cm
Temperature	°C
Suspended solids	mg/l
Total phosphate (PO_4)	mg/l
Ammonia	mg/l
Nitrite	mg/l
Fluoride (F^-)	mg/l
Total oxidised nitrogen (TON)	mg/l
Total N	mg/l
Chloride	mg/l
Nitrate	mg/l
Sulfate (SO_4)	mg/l
Total organic carbon (TOC)	mg/l
True colour	mg/l Pt/Co
Sodium (Na)	mg/l
Magnesium (Mg)	mg/l
Potassium (K)	mg/l
Calcium (Ca)	mg/l
Total hardness	mg/l $CaCO_3$
Alkalinity	mg/l CaCO3
Salinity[1]	ppt
Dissolved inorganic nitrogen (DIN)[1]	mg/l
Chlorophyll-*a*[1]	mg/m³

[1]Additional parameters analysed by the Environmental Protection Agency (EPA).

Appendix 2

A2.1 DEPLOY Publicity

During the 18-month DEPLOY project, its successes were recognised both nationally and internationally. DEPLOY has featured in national television reports, national papers, internet articles and international magazines and news features. These include the following:

- **RTE national news** (http://www.rte.ie/news/2009/0818/9news_av.html?2596165,null,230)
- **National Geographic News** (http://news.nationalgeographic.com/news/2009/12/091205-wireless-river-water-pollution/)
- **New York Times**
- **Silicon Republic** (http://www.siliconrepublic.com/green-tech/item/14532-dcu-technology-could-offset)
- **AlphaGalileo** (http://www.alphagalileo.org/ViewItem.aspx?ItemId=61702&CultureCode=en)
- **Business & Leadership** (http://www.businessandleadership.com/news/article/17921/leadership/dcu-technology-could-offset-future-flood-chaos)
- **Irish Examiner** (http://www.irishexaminer.com/ireland/testing-of-early-warning-systems-106562.html)
- **Sunday Business Post**

A2.2 Presentations

Lawlor, A., *DEPLOY – Smart Catchment Demonstration: Long-Term Deployment of Sensor Monitoring System*. Invited Talk at Sensor Systems for Environmental Monitoring Conference, Royal Society of Chemistry, Burlington House, London, UK, 14 October 2010.

Lawlor, A., *DEPLOY – Smart Catchment Demonstration: Long-Term Deployment of Sensor Monitoring System*. Invited Talk EPA National Research Conference 2010. Science into Action for a Sustainable Ireland, Croke Park Convention Centre, Dublin, Ireland, 23 June 2010.

O'Flynn, B., DEPLOY – *Real-Time Monitoring of Our Waterways for Event Detection and Management.* Invited Talk at Inaugural National Emergency and Flood Risk Management Conference, Croke Park Convention Centre, Dublin, Ireland, 25–26 May, 2010.

Lawlor, A., *Smart Catchment Demonstration: Long-Term Deployment of Sensor Monitoring System (DEPLOY)*. Invited Talk at Green Chemistry in Ireland, Dublin City University, Dublin, Ireland, 15 April 2010.

Regan, F., Lawlor, A., O'Flynn, B., Torres, J., Martinez-Catala, R., O'Mathuna, C. and Wallace, J., *A Demonstration of Wireless Sensing for Long-Term Monitoring of Water Quality*. The 4th IEEE International Workshop on Practical Issues In Building Sensor Network Applications (SenseApp 2009), Zurich, Switzerland, 20–23 October 2009.

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A2.3 Posters

O'Flynn, B., Regan, F., Wallace, J., Lawlor, A. and Sanchez, J.T., *DEPLOY – Real-Time Monitoring of Our Waterways for Event Detection and Management*. In 34th International Microelectronics and Packaging IMAPS-CPMT Conference, Wrocław, Poland, 22–25 September 2010.

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A2.4 Papers

O'Flynn, B., Regan, F., Lawlor, A., Wallace, J., Torres, J. and O'Mathuna, C., 2010. Experiences and recommendations in deploying a real-time, water quality monitoring system. *Measurement Science and Technology* **21**. doi:10.1088/0957-0233/21/12/124004

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An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil, Pobal agus Rialtais Áitiúil.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail;
- scardadh dramhuisce.

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

National Development Plan 2007 - 2013

Science, Technology, Research and Innovation for the Environment (STRIVE) 2007-2013

The Science, Technology, Research and Innovation for the Environment (STRIVE) programme covers the period 2007 to 2013.

The programme comprises three key measures: Sustainable Development, Cleaner Production and Environmental Technologies, and A Healthy Environment; together with two supporting measures: EPA Environmental Research Centre (ERC) and Capacity & Capability Building. The seven principal thematic areas for the programme are Climate Change; Waste, Resource Management and Chemicals; Water Quality and the Aquatic Environment; Air Quality, Atmospheric Deposition and Noise; Impacts on Biodiversity; Soils and Land-use; and Socio-economic Considerations. In addition, other emerging issues will be addressed as the need arises.

The funding for the programme (approximately €100 million) comes from the Environmental Research Sub-Programme of the National Development Plan (NDP), the Inter-Departmental Committee for the Strategy for Science, Technology and Innovation (IDC-SSTI); and EPA core funding and co-funding by economic sectors.

The EPA has a statutory role to co-ordinate environmental research in Ireland and is organising and administering the STRIVE programme on behalf of the Department of the Environment, Heritage and Local Government.

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An Ghníomhaireacht um Chaomhnú Comhshaoil

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